EASTERN CANADIAN BOREAL AND SUB-ARCTIC WETLANDS: A RESOURCE DOCUMENT

Environment Canada
Atmospheric Environment Service

Environnement Canada
Service de l'environnement atmosphérique

C I R A C
Canadian Institute for Research in Atmospheric Chemistry

92-00087/

EASTERN CANADIAN BOREAL AND SUB-ARCTIC WETLANDS: A RESOURCE DOCUMENT

Edited by

Linda Mortsch

CLIMATOLOGICAL STUDIES
NUMBER 42

1990

U.D.C. 551.312

Published by Authority of the Minister of the Environment

© Minister of Supply and Services Canada 1991

Catalogue No. EN57-7/42E
ISBN 0-662-18473-4
ISSN 0068-7715

Printed on recycled paper
Imprimé sur du papier recyclé

PREFACE

The Canadian Northern Wetlands Study (NOWES) is a comprehensive research program whose objective is to assess the role of Canadian wetlands as sources of biogenoic gases under current and future climate scenarios. The research program was developed in January 1988 at the Northern Canadian Wetlands Workshop which was convened by the Canadian Institute for Research in Atmospheric Chemistry (CIRAC), the Atmospheric Environment Service (AES) of Environment Canada and the Royal Society of Canada. The NOWES is recognized internationally as a major project in the International Global Atmospheric Chemistry Program (IGAC) which is part of the International Geosphere-Biosphere Program (IGBP) on Global Change. Ground-based flux studies and aircraft flux observations will be the focus of an intensive summer field program in 1990. Air chemistry observations at Fraserdale, Ontario and remote sensing, ecosystem characterization and modelling activities will take place throughout the duration of the study from 1989 to 1991.

For a study of this scope, a resource document summarizing the major natural resource characteristics of the NOWES region would provide valuable background information. In Chapter 1, the role of wetlands in the changing atmosphere issue is briefly described. Also, the organization of the resource book and a guide to its use are outlined. Chapter 2 summarizes the climate, air chemistry, physiography, geology, hydrology, soils, vegetation and socio-economic characteristics in maps with accompanying descriptive text. This section was designed to provide a very general overview of the NOWES region. In Chapter 3, the 7 main wetland regions within the NOWES are described with respect to their environmental setting, typical wetland types and wetland characteristics. A toposequence is presented for each region which is a conceptual diagram of the relationship between wetland types, landforms and soils.

Funding support for this resource document has been provided by the Canadian Climate Centre and the Atmospheric Research Directorate of AES, Environment Canada and CIRAC.

In the preparation of this resource document, many people contributed their expertise, ideas, comments and suggestions. Dr. Len Barrie and Mr. Bruce Findlay of AES deserve special credit as the catalysts for this book. Daryl Cowell of Geomatics International Inc. had the task of preparing a large portion of the manuscript. Numerous other people contributed to this resource document: Clayton Rubec, N. Loupoukhine and Robert Hélie of the Sustainable Development Branch, Environment Canada assisted with Landsat images and map materials; Rawling Communications prepared the design and layout of maps and graphics. In the Canadian Climate Centre of AES, special thanks should go to Mike Webb for supplying climate data; Eileen Veinot for data abstraction and analysis; Krystyna Czaja for graphics and printing coordination; Janet Issac for providing bioclimatic profiles; Bob Vet for providing maps of atmospheric chemistry deposition, Candi Zell for library support; and Albert Wright for his invaluable production, design, and printing assistance.

The constructive technical review comments of W. Glooschenko of National Hydrology Research Institute, A. Judge of Geological Survey of Canada, N. Roulet of York University, R. Protz of the University of Guelph, and T. Agnew, D. Etkin, B. Findlay, P. Louie, B. Maxwell, A. Saulesleja and V. Swail of AES are gratefully acknowledged.

Linda Mortsch
Downsview, Ontario

DEDICATION

Dedicated to Patrick and Allison Walker.

TABLE OF CONTENTS

Preface . . . iii
List of Contributors . . . viii
List of Maps . . . ix
List of Figures . . . x
List of Tables . . . xi
List of Landsat Images . . . xii

CHAPTER 1

INTRODUCTION . . . 1

- **1.1 Background** . . . 2
- **1.2 Study Area** . . . 4
- **1.3 Organization of the Resource Document** . . . 6
- **1.4 Map and Data Sources** . . . 6
- **1.5 Purpose and Use of the Document** . . . 6
- **1.6 References** . . . 6

CHAPTER 2

OVERVIEW THEME MAPS . . . 9

- **2.1 Introduction** . . . 10
  - 2.1.1 Reference . . . 10
- **2.2 Socio-economic Characteristics** . . . 10
  - 2.2.1 Population . . . 15
  - 2.2.2 Agriculture . . . 15
  - 2.2.3 Forestry . . . 16
  - 2.2.4 Mining . . . 16
  - 2.2.5 Transportation . . . 16
  - 2.2.6 Energy Generation and Consumption . . . 17
  - 2.2.7 References . . . 18
- **2.3 Climate** . . . 18
  - 2.3.1 Solar Radiation . . . 18
  - 2.3.2 Temperature . . . 19
    - 2.3.2.1 January . . . 20
    - 2.3.2.2 July . . . 20
  - 2.3.3 Growing Degree-Days . . . 20
  - 2.3.4 Wind . . . 35
  - 2.3.5 Precipitation . . . 36
  - 2.3.6 References . . . 47

CHAPTER 2 (cont'd)

OVERVIEW THEME MAPS (cont'd)

2.4 Air Chemistry 47
- 2.4.1 Emissions and Deposition of SO_2, NO_x and Reaction Products 48
- 2.4.2 The Atmospheric Region of Influence for the Hudson Bay Lowland 48
  - 2.4.2.1 The One-Day Region of Influence 48
  - 2.4.2.2 Extended Region of Influence 48
- 2.4.3 Direction of Air-Mass Arrival 57
- 2.4.4 Seasonal Variations in Air Movement 57
- 2.4.5 Conclusions 57
- 2.4.6 References 57

2.5 Physiography, Bedrock Geology and Surficial Geology 58
- 2.5.1 Relief 58
- 2.5.2 Physiography 58
  - 2.5.2.1 James Region (J) 58
  - 2.5.2.2 Hudson Region (H) 58
  - 2.5.2.3 Laurentian Region (L) 67
  - 2.5.2.4 Kazan Region (K) 67
  - 2.5.2.5 Davis Region (D) 67
  - 2.5.2.6 Interior Plains Region (I) 67
- 2.5.3 Bedrock Geology 67
  - 2.5.3.1 Canadian Shield 68
  - 2.5.3.2 Interior Platform 70
  - 2.5.3.3 Hudson Platform 70
- 2.5.4 Surficial Geology 70
- 2.5.5 References 75

2.6 Soils and Permafrost 76
- 2.6.1 Soils and Soil Climates 76
  - 2.6.1.1 Soil Types, Distribution and Development 76
  - 2.6.1.2 Soil Climates 80
- 2.6.2 Permafrost 83
- 2.6.3 References 84

2.7 Hydrology 87
- 2.7.1 Drainage Basins 87
- 2.7.2 Annual Runoff 87
- 2.7.3 Water Balance 90
- 2.7.4 River and Lake Freeze-Over and Ice-Free 97
- 2.7.5 Wetland Hydrology 97
  - 2.7.5.1 General Factors 97
  - 2.7.5.2 Basin Flow Regime 101
  - 2.7.5.3 River Break-Up Considerations 102
- 2.7.6 References 102

2.8 Vegetation 103
- 2.8.1 Tundra and Boreal Forest Transition 103
- 2.8.2 Boreal Forest 104
- 2.8.3 Southeastern Mixed Forest (Great Lakes — St. Lawrence Forest) 104
- 2.8.4 Grasslands 104
- 2.8.5 References 104

CHAPTER 3

WETLAND REGION DESCRIPTIONS 107
- **3.1 Wetland Distribution and Wetland Regions** 108
- **3.2 Sub-Arctic Wetlands** 111
  - 3.2.1 High Sub-Arctic Wetland Region 112
    - 3.2.1.1 Environmental Setting 112
    - 3.2.1.2 Wetland Characteristics 113
    - 3.2.1.3 Wetland Types 114
    - 3.2.1.4 High Sub-Arctic Toposequence 118
  - 3.2.2 Low Sub-Arctic Wetland Region 118
    - 3.2.2.1 Environmental Setting 118
    - 3.2.2.2 Wetland Characteristics 123
    - 3.2.2.3 Wetland Types 125
    - 3.2.2.4 Low Sub-Arctic Toposequence 127
  - 3.2.3 Atlantic Sub-Arctic Wetland Region 129
    - 3.2.3.1 Environmental Setting 129
    - 3.2.3.2 Wetland Characteristics 131
    - 3.2.3.3 Wetland Types 131
    - 3.2.3.4 Atlantic Sub-Arctic Toposequence 133
- **3.3 Boreal Wetlands** 133
  - 3.3.1 High Boreal Wetland Region 133
    - 3.3.1.1 Environmental Setting 133
    - 3.3.1.2 Wetland Characteristics 136
    - 3.3.1.3 Wetland Types 138
    - 3.3.1.4 High Boreal Toposequence 140
  - 3.3.2 Mid Boreal Wetland Region 140
    - 3.3.2.1 Environmental Setting 140
    - 3.3.2.2 Wetland Characteristics 143
    - 3.3.2.3 Wetland Types 145
    - 3.3.2.4 Mid Boreal Toposequence 148
  - 3.3.3 Low Boreal Wetland Region 148
    - 3.3.3.1 Environmental Setting 148
    - 3.3.3.2 Wetland Characteristics 151
    - 3.3.3.3 Wetland Types 151
    - 3.3.3.4 Low Boreal Toposequence 153
  - 3.3.4 Atlantic Boreal Wetland Region 156
    - 3.3.4.1 Environmental Setting 156
    - 3.3.4.2 Wetland Characteristics 157
    - 3.3.4.3 Wetland Types 159
    - 3.3.4.4 Atlantic Boreal Toposequence 160
- **3.4 References** 160

GLOSSARY 167

LIST OF CONTRIBUTORS

Chapter 2
Atmospheric Chemistry

Dr. Len Barrie
Atmospheric Research Directorate
Atmospheric Environment Service
4905 Dufferin St.
Downsview, Ontario

Principal Author

Daryl Cowell
Geomatics International Inc.
3370 South Service Road
Burlington, Ontario

Chapters 2 & 3
Climatology; Scientific Liaison, editor

Linda Mortsch
Canadian Climate Centre
Atmospheric Environment Service
4905 Dufferin St
Downsview, Ontario

Chapter 2
Air Mass Trajectories

Dr. Peter Summers
Atmospheric Research Directorate
Atmospheric Environment Service
4905 Dufferin St
Downsview, Ontario

Chapter 1
Project Manager

Greg Wickware
Geomatics International Inc.
3370 South Service Road
Burlington, Ontario

PHOTO CREDITS

COVER: Front — D. Cowell

Back: — H. Hirvonen (Bottom photo)
D. Cowell (All others)

LIST OF MAPS

Map 2.2.1 Location of communities, airports, rivers and lakes 11

Map 2.2.2 Location of mineral mines, resource processing and electric generating stations 13

Map 2.3.1A Annual global solar radiation and mean annual net radiation 21

Map 2.3.1B Monthly percent frequency of cloud amounts at selected climate stations 23

Map 2.3.1C July hourly percent frequency of clear sky and overcast conditions 25

Map 2.3.2A Mean daily temperature — January 27

Map 2.3.2B Mean daily temperature — July 29

Map 2.3.2C Mean monthly air temperature statistics for selected climate stations ... 31

Map 2.3.3 Annual total growing degree-days above 5°C 33

Map 2.3.4A Frequency of wind speed (knots) by direction — Winter 37

Map 2.3.4B Frequency of wind speed (knots) by direction — Summer 39

Map 2.3.5A Mean annual total precipitation 41

Map 2.3.5B Mean annual snowfall and mean maximum depth of snow 43

Map 2.3.5C Mean monthly total precipitation at selected climate stations 45

Map 2.4.1 North American SO_2 and NO_x annual emissions — 1980 49

Map 2.4.2 Wet deposition of acids to wetlands 51

Map 2.4.3 Atmospheric Regions of Influence (AROI) for 1-day travel distance of air 53

Map 2.4.4 Most probable atmospheric regions of influence for 1 to 5 days 55

Map 2.4.5 The frequency of occurrence of the origin of Air Parcels for 1 day and 5 days back in time stratified by the 8 directional sections. 59

Map 2.4.6 Seasonal variations in the 5 day median travel distance of an air parcel to Fraserdale. 61

Map 2.5.1 Generalized relief 63

Map 2.5.2 Physiographic regions and divisions 65

Map 2.5.3 Bedrock geology 71

Map 2.5.4 Surficial geology 73

Map 2.6.1 Soils 77

Map 2.6.2 Soil climates — temperature and moisture 81

Map 2.6.3 Permafrost 85

Map 2.7.1 Drainage basins and diversions 91

Map 2.7.2 Annual runoff 93

Map 2.7.3 Water balance — derived precipitation and evapotranspiration 95

Map 2.7.4 Mean dates of freeze-over and ice-free for lakes and rivers 99

Map 2.8.1 Vegetation regions and forest sections 105

Map 3.1.1 Wetland regions and percentage cover of wetlands 109

LIST OF FIGURES

Figure 1.1 Concentrations of CO_2 and CH_4 in the atmosphere. Observed atmospheric concentrations of CO_2 and observed and calculated concentrations of CH_4 in the atmosphere 3

Figure 1.2 Distribution of wetlands within the Northern Wetlands Study area 4

Figure 1.3 Worldwide distribution of wetlands 5

Figure 2.5.1 Structural provinces of the Precambrian in eastern North America showing the location of the Northern Wetlands Study area. Overlying Paleozoic sedimentary rocks are excluded 69

Figure 2.7.1 Conceptual model showing the role of hydrology in wetland ecosystems and the modification of hydrology by wetland processes 98

Figure 3.2.1 Schematic cross section through the High Sub-arctic Wetland Region representing the Hudson Bay Lowland portion near Peawanuck (formerly Winisk), Ontario 119

Figure 3.2.2 Relationship between distance from the coast and depth of peat as measured in fen types for the Hudson Bay Lowland. Data presented for the area south of the Albany River in the south-western James Bay area (Low Sub-arctic Wetland Region) and in the vicinity of the Winisk River (High Sub-arctic Wetland Region) 124

Figure 3.2.3 Schematic cross section through the Low Sub-arctic Wetland Region representing the Hudson Bay Lowland portion near Moosonee, Ontario 128

Figure 3.2.4 Toposequence for the Atlantic Sub-arctic Wetland Region (Atlantic plateau bog) 134

Figure 3.3.1 Toposequence for the High Boreal Wetland Region illustrating relationships among soils, vegetation physiognomy and landform for bedrock-controlled upland, drumlinized till plain and glaciolacustrine plain in north-central Manitoba 141

Figure 3.3.2 Toposequence for the Mid Boreal Wetland Region illustrating relationships among soils, wetland physiognomy and landform for the clay belt glaciolacustrine plain in northeastern Ontario and western Québec 149

Figure 3.3.3 Toposequence for the Low Boreal Wetland Region illustrating the relationships among soils, wetland types and landform in the bedrock-controlled terrain of the Experimental Lakes area research site 154

Figure 3.3.4 Toposequence for the Atlantic Boreal Wetland Region 161

LIST OF TABLES

Table 2.2.1 Selected socio-economic statistics for the Northern Wetlands Study area. 15
Table 2.2.2 Major reservoirs within the Northern Wetlands Study area. 17
Table 2.3.1 Fraction of solar radiation reflected (albedo) by various surfaces. 18
Table 2.3.2 Growing season climate information for the period 1951-1980. 35
Table 2.6.1 Characteristics of the four soil temperature classes occurring in the Northern Wetlands Study area (see Map 2.6.2). 80
Table 2.7.1 Major river basins and drainage areas of the Northern Wetlands Study area. 88
Table 2.7.2 Drainage diversions within the Northern Wetlands Study area. 89
Table 3.2.1 High Sub-arctic Wetland Region climate statistics. 113
Table 3.2.2 Wetland characteristics of the High Sub-arctic Wetland Region. 115
Table 3.2.3 Means (standard deviations) for peat depth, depth to water table and groundwater pH for marsh, swamp, fen and bog types in the High Sub-arctic portion of the Hudson Bay Lowland (Ontario). 116
Table 3.2.4 Low Sub-arctic Wetland Region climate statistics. 121
Table 3.2.5 Wetland Characteristics of the Low Sub-arctic Wetland Region. 122
Table 3.2.6 Means (standard deviations) for groundwater chemistry, peat thickness and depth to water table for conifer swamp, fen and bog types in the Low Sub-arctic portion of the Ontario Hudson Bay Lowland (south of the Albany River). 125
Table 3.2.7 Atlantic Sub-arctic Wetland Region climate statistics. 129
Table 3.2.8 Wetland and soil characteristics of the Atlantic Sub-arctic Wetland Region. 132
Table 3.3.1 High Boreal Wetland Region climate statistics. 135
Table 3.3.2 Wetland characteristics of the High Boreal Wetland Region. 137
Table 3.3.3 Mid Boreal Wetland Region climate statistics. 142
Table 3.3.4 Wetland characteristics of the Mid Boreal Wetland Region. 144
Table 3.3.5 Means and ranges of depth to water table, peat depth, peat humification and groundwater pH and calcium concentration for physiognomic wetland types in the Kinosheo Lake area. 146
Table 3.3.6 Low Boreal Wetland Region climate statistics. 150
Table 3.3.7 Wetland characteristics of the Low Boreal Wetland Region. 152
Table 3.3.8 Means (standard deviations) for bog (basin bog), fen (basin fens), marshes and conifer swamps in the Experimental Lake Area near Kenora, Ontario. 153
Table 3.3.9 Atlantic Boreal Wetland Region climate statistics. 156
Table 3.3.10 Wetland characteristics of the Atlantic Boreal Wetland Region. 158

LIST OF LANDSAT IMAGES

Image 3.2.1 Landsat multispectral image (bands 4, 5 and 7) of the High Sub-arctic at Churchill Manitoba. The townsite of Churchill is located immediately east of the Churchill River (centre of image) at its outlet to Hudson Bay. The image was recorded on October 14, 1975 at a scale of 1:1 million. 120

Image 3.2.2 Landsat multispectral image (bands 4, 5 and 7) of the Low Sub-arctic and Mid Boreal of southwestern James Bay. The townsite of Moosonee is located on the west bank of the Moose River approximately 20 km upstream of James Bay (light tone on outside of river bend). Kinosheo Lake is the large lake located in the left centre of the image. The image was recorded on September 29, 1976 at a scale of 1:1 million. 130

Image 3.3.1 Landsat multispectral image (bands 4, 5 and 7) of the Low Boreal Wetland Region in the vicinity of Kenora, Ontario. The large lake in the south-central portion of the image is Lake of the Woods with the townsite of Kenora located on its northern shore (light tone, just left of centre). Glaciolacustrine plains of Glacial Lake Agassiz occur in the southwest corner (Manitoba and Minnesota) and in the east centre. Dryden, Ontario is located on the plain immediately east of the image. The image was recorded on November 24, 1975 and is at a scale of 1:1 million. 155

Image 3.3.2 Landsat multispectral image (bands 4, 5 and 7) of the Atlantic Boreal of central Labrador and northeastern Québec. The townsite of Schefferville, Québec is located in the northwest portion of the image immediately west of the large lake complex. The image was recorded on October 17, 1980 at a scale of 1:1 million. 162

CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1 BACKGROUND

The composition of the earth's atmosphere is undergoing major changes as a result of human activities (Environment Canada 1986). These changes include increasing concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), water vapour and chloro-fluorocarbons (CFC's) (Hansen *et al.* 1989). An increase in these gases enhances the capability of the atmosphere to absorb heat energy radiated from the surface of the earth. A likely consequence is the substantial alteration of global climate including global warming.

Although industrial activity is believed to be the major source of these gases, methane, nitrous oxide and carbon dioxide are also generated by biological processes. The role of natural sources and sinks of these and other gases is not well understood. Wetlands are known to produce both CO_2 and CH_4 and, hence, the role of wetlands in the global cycling of these gases must be fully evaluated before predictive models of climate change can be developed.

The concentration of CH_4 in the earth's atmosphere is increasing at about 1.0 percent per year (Khalil and Rasmussen 1990). After remaining relatively constant for more than 10,000 years, it has doubled since the beginning of the 20th century (Figure 1.1). Levels of CO_2 have increased about 15 percent between 1950 and 1988 (Flavin 1989, Figure 1.1).

Methane is a gas which absorbs infrared radiation in the "window" region where CO_2 does not absorb appreciably. Increased CH_4 concentrations can therefore contribute significantly to the greenhouse effect. Positive feedback mechanisms exist which can magnify climatic effects. For example, increases in CO and CH_4 result in a decrease in the atmospheric concentration of hydroxyl radicals which are major scavengers for CH_4 and other radiatively active gases (Khalil and Rasmussen 1985).

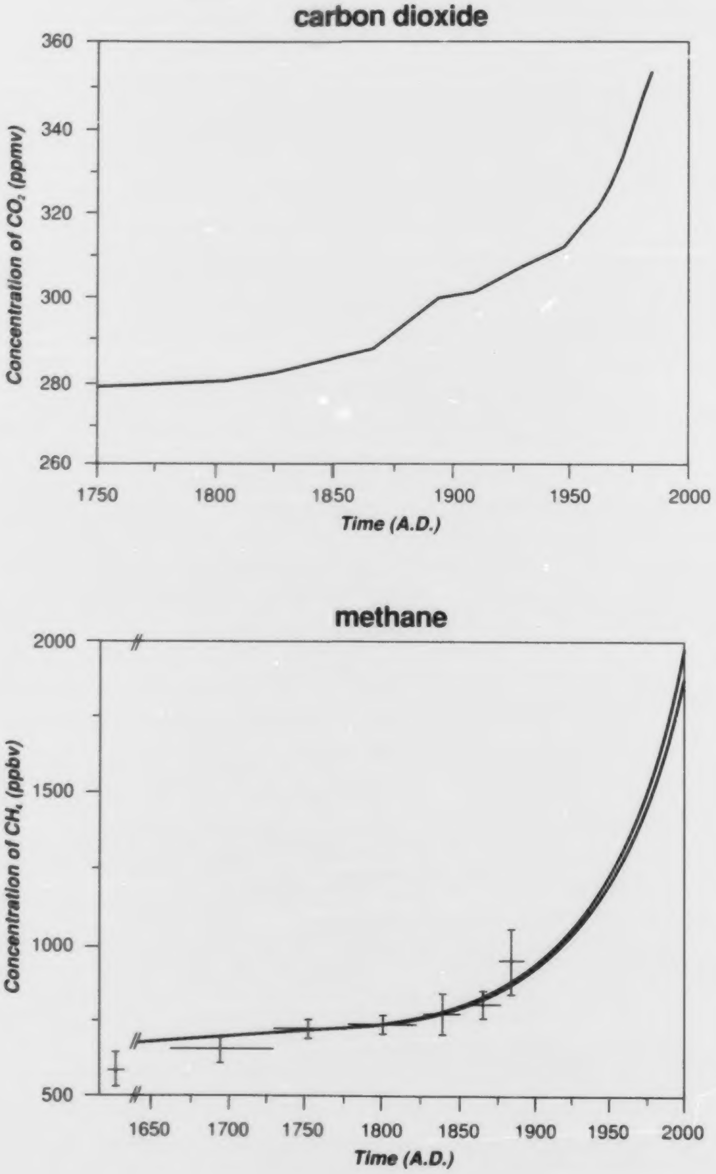
Methane is formed primarily through anaerobic biological processes. Wetlands, and in particular peatlands, represent a major ecological entity whose processes of formation and development are typically carried out under anaerobic conditions. It is estimated that wetlands account for 15 to 40 percent of the total global atmospheric volume of CH_4. Sebacher *et al.* (1986) estimate that northern wetlands contribute 45 to 106 $\times 10^{12}$ g CH_4 yr^{-1} to the global troposphere. Matthews and Fung (1987) estimate the global contribution of CH_4 from wetlands to be closer to 110 $\times 10^{12}$ g yr^{-1} of which 65 $\times 10^{12}$ g CH_4 yr^{-1} are contributed by wetlands located north of 50°N latitude. More recent estimates by Aselmann and Crutzen (1989) put the annual global contribution of CH_4 from wetlands at between 40 and 160 $\times 10^{12}$ g with an additional 60 to 140 $\times 10^{12}$ g annually from rice paddies.

There is a significant data gap with regard to specific fluxes of CH_4 and CO_2 from a representative range of wetland types. This information is required to determine the relative importance of wetlands in the global warming process (Moore and Knowles 1988). Of particular interest is the development of measurement techniques for determining large-area CH_4 and CO_2 fluxes from peatlands to the atmosphere in order to understand how climatic warming might influence the production and emission of CH_4 from northern peatlands (Harriss 1988, Gorham 1988). For example, the dependence of wetland CH_4 fluxes on nutrient content of the water, the quantity and composition of organic matter, soil moisture, soil temperature, vegetation type and water table are not well understood (Harriss 1988).

The vast wetland, peat and tundra areas of northern regions can also influence the concentration of other important gases in the global atmosphere. Very little is known about air-surface exchanges of CO_2 or of nitrogen and sulphur-containing gases within this ecosystem which can affect the complex chemistry of the global atmosphere as well as impact climate (Schiff and Barrie 1988). The Northern Wetlands Study (NOWES) was developed as a comprehensive research program to determine the role of Canadian wetlands in affecting physical and chemical change in the environment.

FIGURE 1.1

Concentrations of CO_2 and CH_4 in the atmosphere. Observed atmospheric concentrations of CO_2 and observed and calculated concentrations of CH_4 in the atmosphere (from Flavin 1989 and Khalil and Rasmussen 1985, respectively).



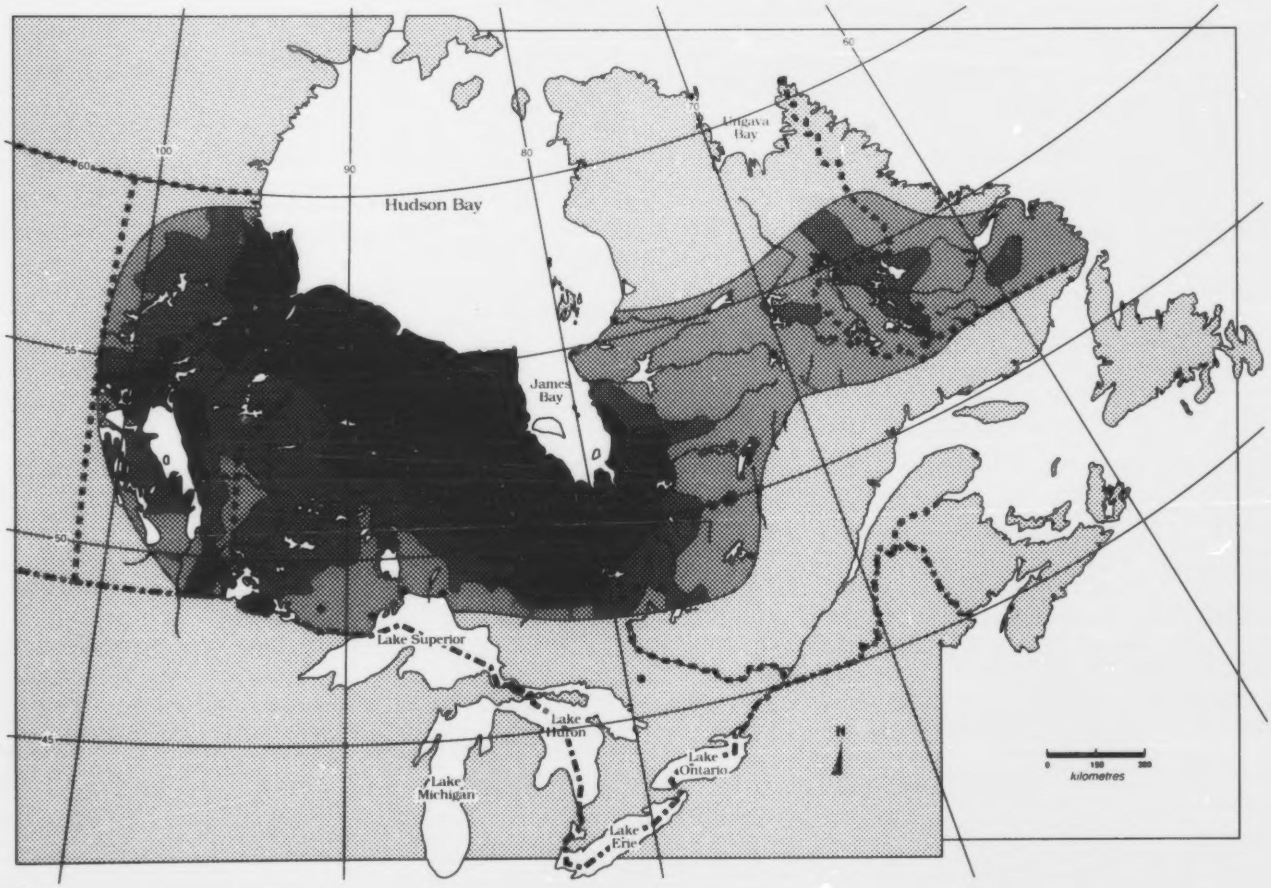
1.2 STUDY AREA

The Northern Wetlands Study focuses on those areas in the provinces of Manitoba, Ontario, Québec and Newfoundland (Labrador) where wetlands form a significant component of the land surface. Figure 1.2 shows the distribution of wetlands within the study area. Over half of the Northern Wetlands Study area, particularly in Manitoba and Ontario, have a wetland cover greater than 26 percent ranging up to 100 percent (National Wetlands Working Group 1986). Areas with wetland distribution of 25 percent or less occur mostly on the Canadian Shield in Québec and Labrador.

The study area is located within the boreal and sub-arctic regions of Canada as defined by the National Wetlands Working Group (NWWG 1986). These mid latitude regions, occurring between 45 and 75°N, tend to have the highest concentration of wetlands throughout the world (Bramryd 1980, Gore 1983). Figure 1.3 illustrates the global distribution of wetlands including both peatlands and non-peatland types. The Northern Wetlands Study area lies within the region shown as

FIGURE 1.2

Distribution of wetlands within the Northern Wetlands Study area (from National Wetlands Working Group 1986)



▨ 6-25% wetland cover

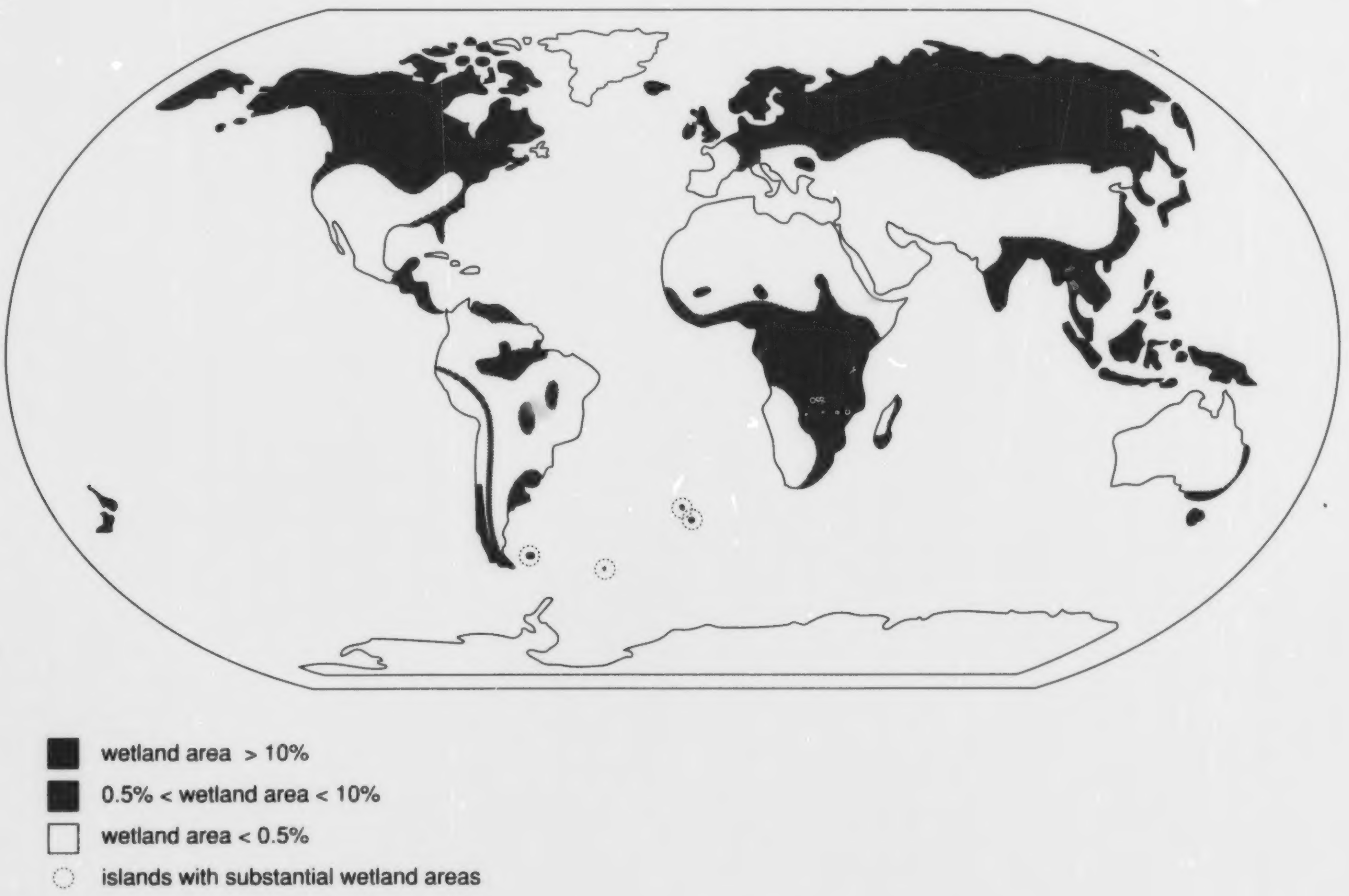
■ 26-50% wetland cover

■ 51-75% wetland cover

■ 76%-100% wetland cover

FIGURE 1.3

Worldwide distribution of wetlands (from Gore 1983)


wetland area > 10%
0.5% < wetland area < 10%
wetland area < 0.5%
islands with substantial wetland areas

having the highest wetland abundance. The study area includes the second largest continuous peatland area in the world, the Hudson Bay Lowland (Riley 1982), located to the south of Hudson Bay. The largest peatland area in the world is located in the West Siberian Plain of the Soviet Union (Neishstadt 1977).

Within the Northern Wetlands Study area, Kinosheo Lake and Churchill in the Hudson Bay Lowland, Schefferville in northeastern Québec and the Experimental Lakes Area in northwestern Ontario are field sites for the research program. Fraserdale, in northeastern Ontario, will be important as a long term baseline air chemistry station. These areas have been the focus of numerous previous and on-going research programs relating specifically to wetlands.

1.3 ORGANIZATION OF THE RESOURCE DOCUMENT

The document is organized into two major sections. Chapter 2 is designed to provide the reader with an overview of the major resource components of the study area primarily through the use of maps. These maps were initially prepared at a scale of 1:5,000,000. Each resource map is accompanied by a brief descriptive summary highlighting the map theme as it pertains to wetlands and, specifically, to the Northern Wetlands Study area. The maps are not designed for detailed analyses but serve primarily to provide a broad regional overview.

Chapter 3 provides detailed descriptions of wetlands occurring within the Northern Wetlands Study area. Wetland Regions, as defined by the National Wetlands Working Group (1986), are used as the framework for this chapter. Each wetland region is described with respect to its environmental setting including physiography, vegetation and soils, climate and permafrost, dominant wetland characteristics and most common wetland types. An idealized toposequence illustrating relationships among wetland vegetation, soils and landforms is provided for each wetland region. Landsat images showing typical terrain conditions in the vicinity of each field site are also provided.

1.4 MAP AND DATA SOURCES

Resource maps presented in Chapter 2 have been prepared using existing information sources. Primary references include the *National Atlas of Canada*, 4th and 5th editions; *Geology and Economic Minerals of Canada; Climatic Atlas Climatique — Canada; Hydrological Atlas of Canada; Soils of Canada; Permafrost in Canada; Canada's Wetlands*; and *Forest Regions of Canada*. Supplemental information was obtained from a variety of provincial and ecological classification maps. Climate, hydrology, bedrock geology, wetlands, permafrost and vegetation information was taken directly from one source each. Soils and surficial geology maps are each a composite of two or more maps.

Sources for each map are cited in the legend and a complete list of references is provided for each major resource section. Data and other descriptive information sources for Chapter 3 are listed at the end of the chapter. The recently published book *Wetlands of Canada* has been used as a major source of information for this chapter.

Summary tables of wetland characteristics are provided for each wetland region described in Chapter 3. The data in these tables have been taken from a wide range of references which are cited in each table. The sources range from regional-scale surveys which are generally specific to each province such as ecological surveys to site specific studies.

1.5 PURPOSE AND USE OF THE DOCUMENT

This document is meant to provide a broad description of landscape, climate and air chemistry components of the Northern Wetlands Study area with specific reference to wetland conditions and characteristics. It is meant to serve as a basic resource document for a diverse range of technical specialists who are involved or interested in the Study. A second major purpose is to provide information for the broad-scale extrapolation of site specific research on CH_4 and CO_2 production in representative wetlands throughout the study area. A glossary of selected technical terms is provided at the end of the document.

1.6 REFERENCES

Aselmann, I. and P.J. Crutzen. 1989. Global distribution of natural freshwater wetlands and rice paddies, their net primary productivity, seasonality and possible methane emissions. *J. Atmos. Chem.*, 8: 307-358.

Bramryd, T. 1980. The role of peatlands for the global carbon dioxide balance. Proc. 6th Int. Peat Congress, August 1980, Duluth, MN: 9-11.

Environment Canada. 1986. The Greenhouse Gases. Fact Sheet, Atmospheric Environment Service, Environment Canada, Downsview, Ontario: 4p.

Environment Canada. 1988. The Changing Atmosphere, implications for global climate. Presented at World Conference, Toronto, Ontario, June 1988, Atmospheric Environment Service, Environment Canada, Downsview, Ontario: 8p.

Flavin, C. 1989. Slowing global warming: a worldwide strategy. World Watch, Paper 91: 94p.

Gore, A.J.P. 1983. Introduction. *In. Ecosystems of the world. Volume 4A. Mires: Swamp, Bog, Fen and Moor.* A.J.P. Gore, editor. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands: 1-34.

Gorham, E. 1988. Processes controlling development and carbon accumulation in northern peatlands. *In. A cooperative Canadian university, government, industry research program on 'The Role of Canadian Wetlands in Influencing the Composition of the Atmosphere and Climate': a workshop report and three year program plan.* Schiff, H.I. and L.A. Barrie, (editors). Can. Instit. Res. Atmos. Chem., York Univ., Toronto, Ontario, Report No. CIRAC/018801: 26-28.

Hansen, J., A. Lacis and M. Prather. 1989. Greenhouse effect of chlorofluorocarbons and other trace gases. *J. Geophys. Res.*, 94 (D13): 16,417-16,421.

Harriss, R.C. 1988. Sources of methane in northern peatlands. *In. A cooperative Canadian university, government, industry research program on 'The Role of Canadian Wetlands in Influencing the Composition of the Atmosphere and Climate': a workshop report and three year program plan.* Schiff, H.I. and L.A. Barrie, (editors). Can. Instit. Res. Atmos. Chem., York Univ., Toronto, Ontario, Report No. CIRAC/018801: 29-33.

Khalil, M.A.K. and R.A. Rasmussen. 1985. Causes of increasing atmospheric methane: depletion of hydroxyl radicals and the rise of emissions. *Atmos. Environ.*, 19(3): 397-407.

Khalil, M.A.K. and R.A. Rasmussen. 1990. Atmospheric methane: recent global trends. *Environmental Science and Technology*, 24(4): 549-553.

Matthews, E. and I. Fung. 1987. Methane emission from natural wetlands: global distribution, area and environmental characteristics of sources. *Global Biogeochem. Cycles*, 1: 61-86.

Moore, T.R. and R. Knowles. 1988. Methane and carbon dioxide evolution from peatlands in eastern Canada. *In. A cooperative Canadian university, government, industry research program on 'The Role of Canadian Wetlands in Influencing the Composition of the Atmosphere and Climate': a workshop report and three year program plan.* Schiff, H.I. and L.A. Barrie, (editors). Can. Instit. Res. Atmos. Chem., York Univ., Toronto, Ontario, Report No. CIRAC/018801: 47-49.

National Wetlands Working Group. 1986. Canada's Wetlands: maps of wetland regions and distribution in Canada. Canada Committee on Ecological Land Classification, Lands Dir., Environment Canada, Ottawa: 2 maps at 1:7.5 m scale plus fact sheet.

Neishstadt, M.I. 1977. The world's largest peat basin, its commercial potentialities and protection. *Int. Peat Soc. Bull.*, 8: 37-43.

Riley, J.L. 1982. Hudson Bay Lowland floristic inventory, wetlands catalogue and conservation strategy. *Le Naturaliste can.*, 109: 543-555.

Schiff, H.I. and L.A. Barrie. 1988. A cooperative Canadian university government industry research program on 'The Role of Canadian Wetlands in Influencing the Composition of the Atmosphere and Climate': a workshop report and three year program plan. Canadian Institute Res. Atmos. Chem., York University, Toronto, Ontario, Report No. CIRAC/018801: 82p.

Sebacher, D.I., R.C. Harriss, K.B. Bartlett, S.M. Sebacher and S.S. Grice. 1986. Atmospheric methane sources: Alaskan tundra bogs, an alpine fen and a sub-arctic boreal marsh. *Tellus*, 38B: 1-10.

CHAPTER 2

OVERVIEW THEME MAPS

OVERVIEW THEME MAPS

2.1 INTRODUCTION

The purpose of this section is to summarize basic resource information on the entire Northern Wetland Study area as well as to relate how factors of climate and landscape affect the distribution and nature of wetlands. The chapter is organized into seven major sections including socio-economic characteristics, climate, air chemistry, geology and physiography, soils and permafrost, hydrology, and vegetation.

The abundance, nature and distribution of wetlands are the product of the interrelationships of the natural resource components. Wetlands are defined as "...land that has the water table at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to the wet environment" (Tarnocai 1980). Wetlands represent areas where soils are waterlogged and vegetation decomposes under anaerobic conditions. Conditions which lead to a higher rate of vegetation production than decomposition result in the net accumulation of organic material and the formation of peatlands.

The essential landscape components required for wetland formation include an excess of precipitation over evapotranspiration, flat-lying topography or depressions in the landscape, and low permeability of underlying soils or bedrock.

Factors which influence the type of wetland formation and the amount of peat accumulation are:

1. the air and soil temperature regimes which affect decomposition rates and the formation of permafrost;
2. the topography and position within the watershed which influence the size of the wetland as well as the rate and quantity of groundwater and surface runoff contributions to the wetland area;
3. the geochemistry of subsurface materials which affects nutrient status; and
4. the age of the wetland.

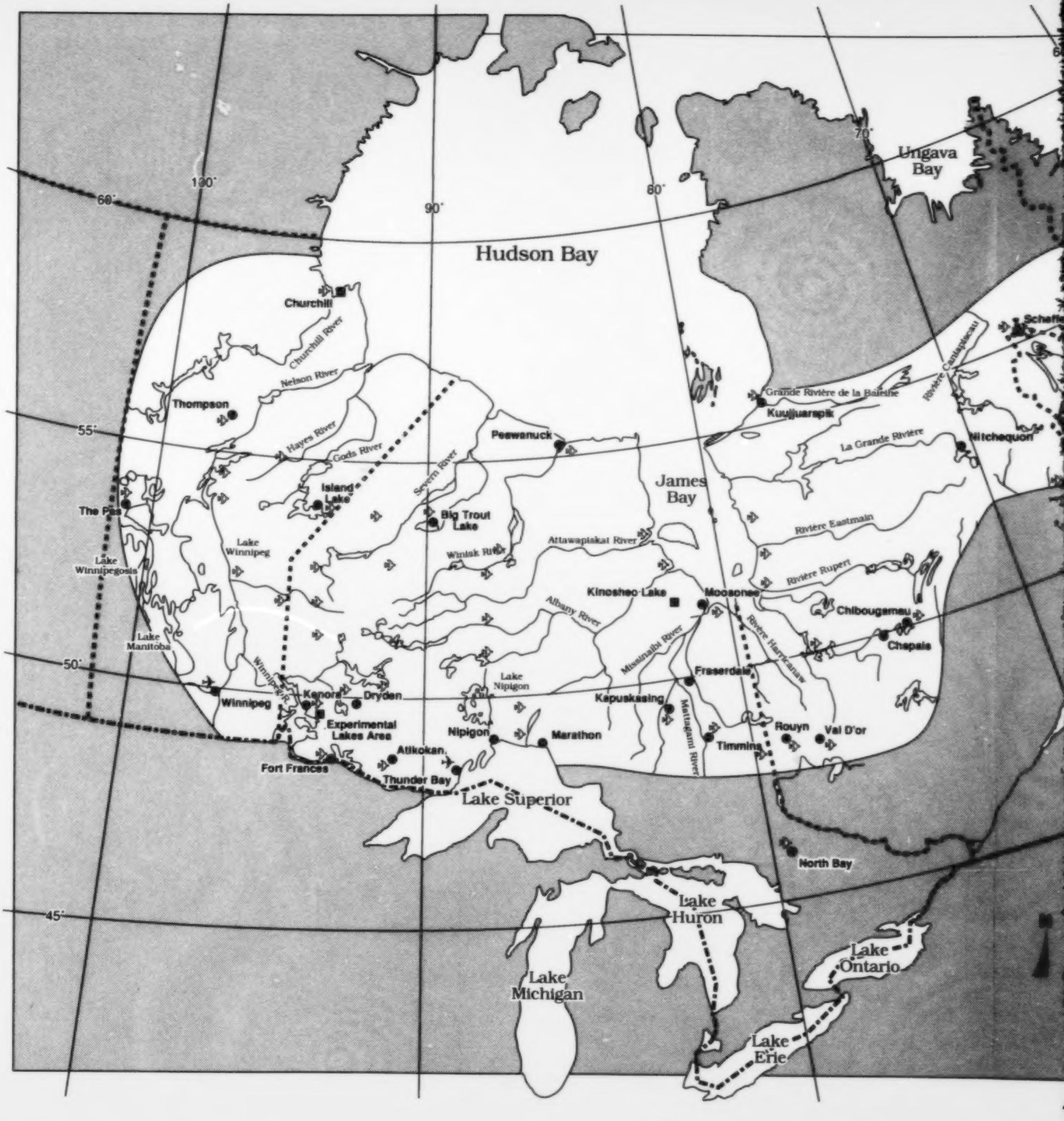
2.1.1 REFERENCE

Tarnocai, C. 1980. Canadian wetland registry. Proc. Workshop on Can. Wetlands, C.D.A. Rubec and F.C. Pollett (eds), Environment Canada, Ecological Land Classification Series, No.12: 9-38.

2.2 SOCIO-ECONOMIC CHARACTERISTICS

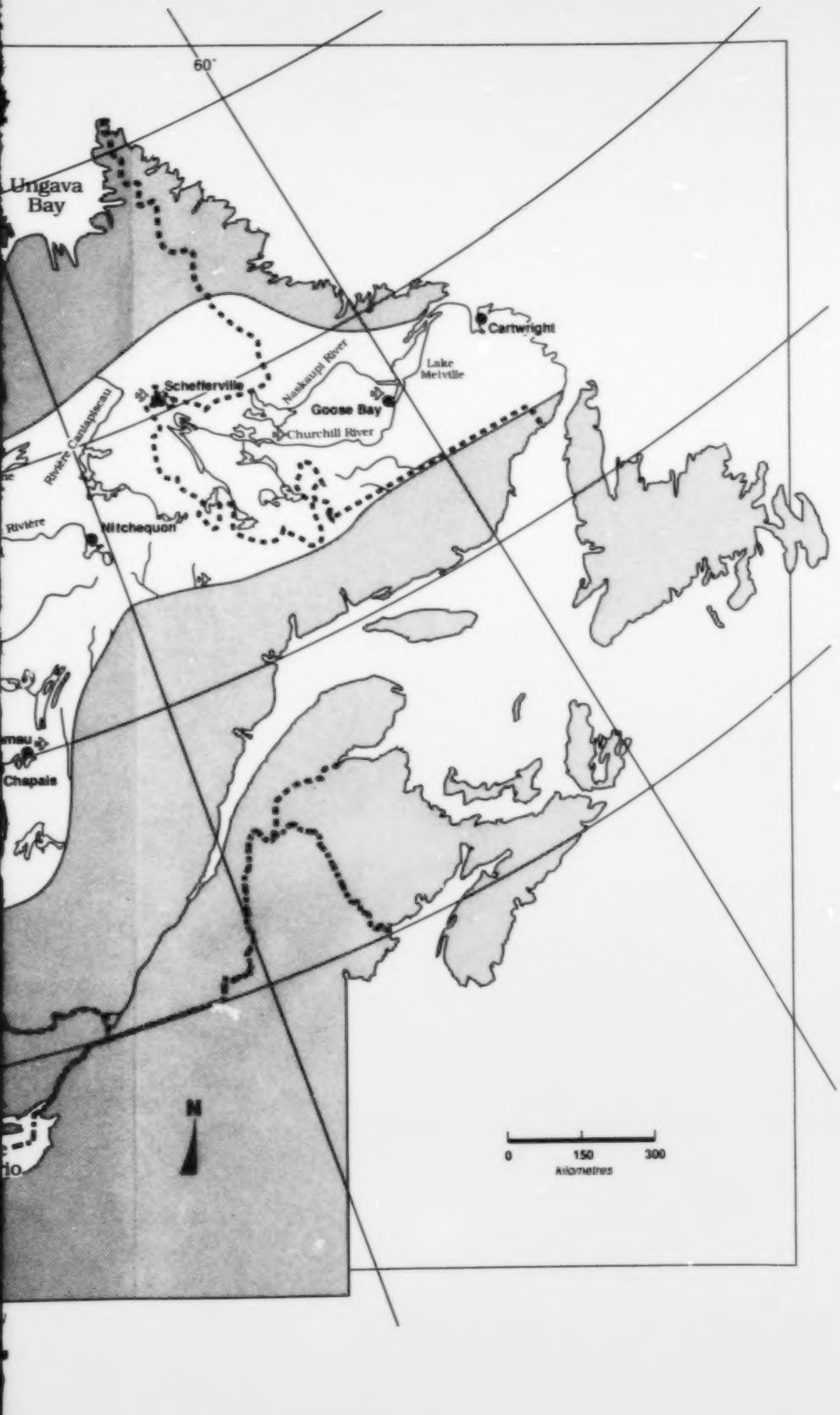
Socio-economic characteristics which are important to the Northern Wetlands Study include land uses which may affect the distribution and abundance of wetlands and activities which, in turn, affect air chemistry. Important land uses include agriculture, forestry and mining whereas important activities are smelting, pulp and paper production and thermal-electric power generation. Map 2.2.1 identifies the location of communities, airports (local, regional and international service) and major lakes and rivers of the study area. Major smelters (ferrous and non-ferrous), pulp and paper mills, mineral mines and thermal and hydro-electric generating stations are shown on Map 2.2.2.

Table 2.2.1 lists the 1981 summary statistics for population, farming, forestry, mining and fossil fuel consumption within the Northern Wetlands Study region. The statistics were tabulated according to 'ecozones' (Statistics Canada 1986). The boundaries of ecozones correspond closely with the Northern Wetlands Study area except along its southern boundary in Québec and Ontario where the 'Boreal Shield' ecozone of Statistics Canada (1986) includes all of the Canadian Shield. The statistics overestimate the data for the Northern Wetlands Study area but provide a convenient overview of socio-economic activities.


Hudson Bay
Ungava Bay
James Bay
60°
100°
90°
80°
70°
55°
50°
45°
Churchill
Churchill River
Nelson River
Thompson
Hayes River
Gods River
Island Lake
Severn River
Big Trout Lake
Peawanuck
The Pas
Lake Winnipeg
Lake Winnipegosis
Lake Manitoba
Winisk River
Attawapiskat River
Albany River
Kinosheo Lake
Moosonee
Grande Rivière de la Baleine
Kuujjuarapik
La Grande Rivière
Nitchequon
Rivière Caniapiscau
Schefferville
Rivière Eastmain
Rivière Rupert
Chibougamau
Chapais
Rivière Harricanaw
Missinaibi River
Fraserdale
Winnipeg R.
Winnipeg
Kenora
Dryden
Experimental Lakes Area
Lake Nipigon
Kapuskasing
Mattagami River
Nipigon
Marathon
Timmins
Rouyn
Val D'or
Atikokan
Fort Frances
Thunder Bay
Lake Superior
North Bay
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie

map 2.21
NORTHERN WETLANDS STUDY AREA

Location of communities, airports, rivers and lakes



■ northern wetlands study area town or research site

● townsite

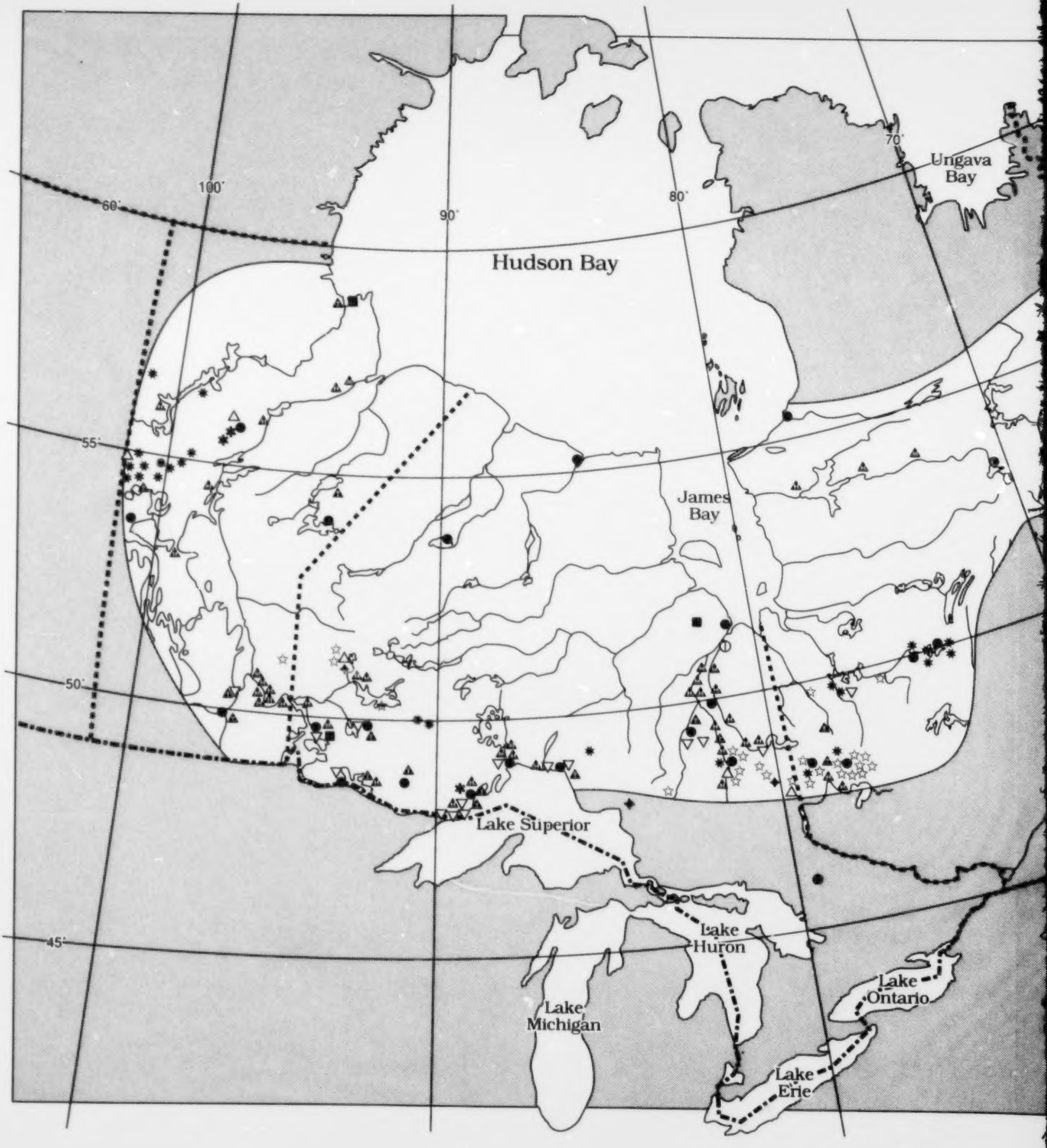
airports

✈ international

➢ regional / local

Source:
National Atlas of Canada, 1:7.5 m,
(Energy, Mines & Resources 1974 and 1985)

Projection: polar stereographic

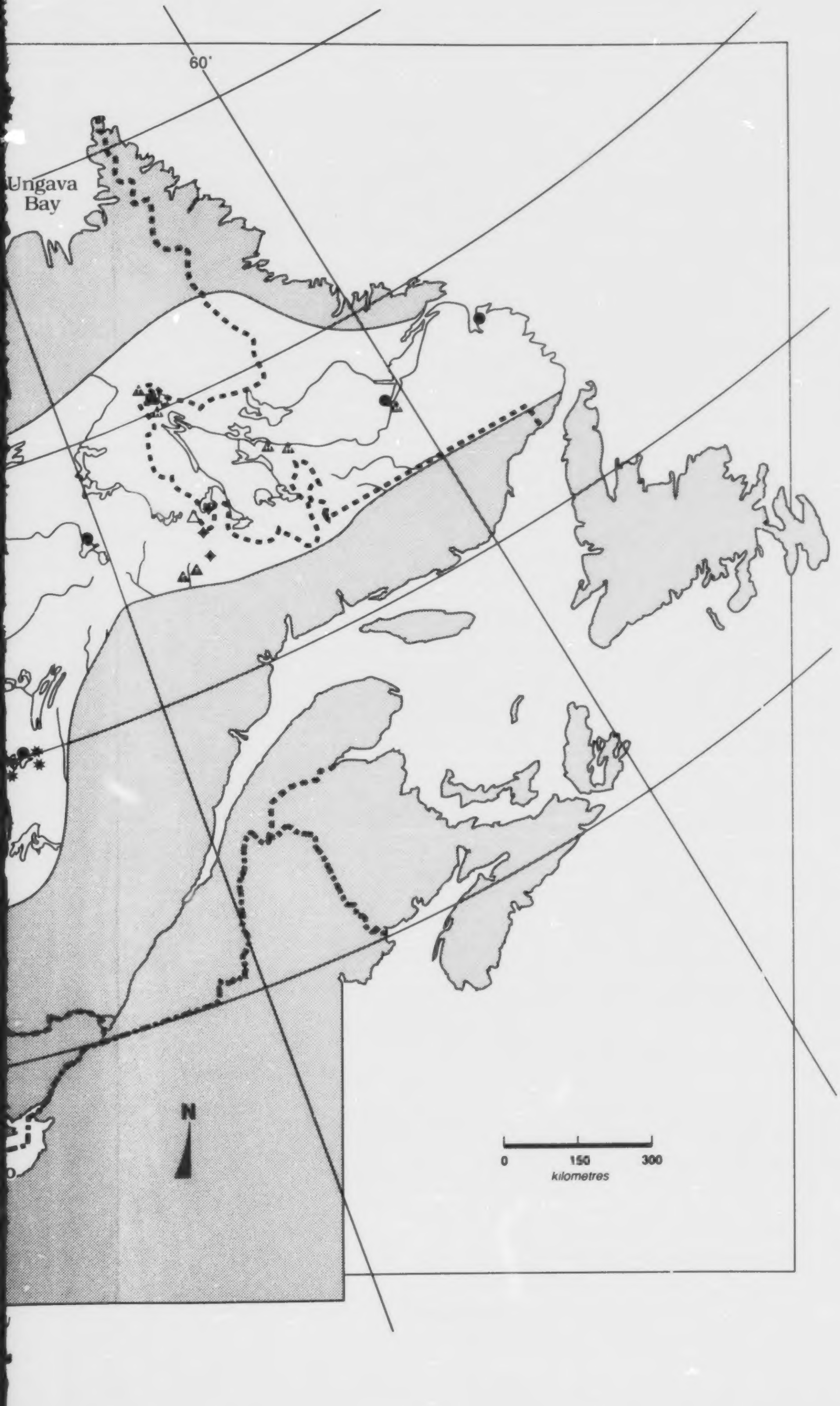


Hudson Bay
James Bay
Ungava Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°

map 2.2.2

NORTHERN WETLANDS STUDY AREA

Location of mineral mines, resource processing and electric generating stations



mineral mines

◆ iron
✷ copper
☆ gold
● zinc
✱ nickel
⦶ Onakawana lignite deposit

processing industry

▽ pulp and paper mill
△ smelter
▲ hydro electric station (greater than 5 MW)
▲ thermal electric station (greater than 5 MW)

Source:
National Atlas of Canada, 1:7.5 m,
(Energy, Mines & Resources 1974 and 1985)

Projection: polar stereographic

Resource based industries including agriculture, forestry, fishing and trapping, mines and quarries, vegetable processing, sawmills, pulp and paper mills, and smelting and refining constitute between 58 and 86 percent of all goods producing industries within the Northern Wetlands Study area (Statistics Canada 1986). The non-resource based industries, such as primary and secondary manufacturing, become more prominent in the south. Winnipeg is the largest manufacturing centre in the study area.

2.2.1 POPULATION

Population estimates shown in Table 2.2.1 were aggregated on the basis of drainage basins. The total population of the Northern Wetlands Study area is approximately 1.35 million. Communities generally consist of less than 25,000 people and are widely scattered (Map 2.2.1). Communities which have more than 25,000 people are Timmins (44,747), Thunder Bay (111,476) and Winnipeg (560,874).

The most densely populated portion of the study area is in south-western Manitoba where population density reaches 12 people/km^2. The remainder of the study area has a population density of less than or equal to 1 person/km^2 (Statistics Canada 1986).

2.2.2 AGRICULTURE

Agricultural activities are important to the Northern Wetlands Study in two ways. Firstly, the conversion of wetlands to agricultural land use results in the reduction of wetland abundance and variability. Secondly, livestock populations may serve as a source of methane to the atmosphere. The area of farmland and populations of cattle and pigs within the study area are listed in Table 2.2.1.

Farmland is very restricted in extent. Only southern Manitoba and small portions of northwestern and northeastern Ontario have substantial agricultural development. Wetlands in southern Manitoba have been

TABLE 2.2.1

Selected socio-economic statistics for the Northern Wetlands Study area*, 1981.

	MANITOBA	ONTARIO	QUEBEC	LABRADOR	TOTAL STUDY AREA	PERCENT OF CANADA'S TOTAL
POPULATION (approx)**	810,000	330,000	183,000	27,000	1,350,000	5.5
AGRICULTURE						
Farmland (ha)	1,620,673	711,165	795,238	-	3,127,076	4.7
Cattle	298,180	188,101	266,077	-	752,358	5.6
Pigs	145,048	24,176	155,302	-	324,526	3.3
FORESTRY						
Productive Forestland (ha) +	134,700	368,200	490,600	45,900	1,039,400	47.5
Productive Forestland Wood Volumes (thousands m^3)						
Softwood	429,998	2,050,143	2,909,379	259,595	5,649,115	36.7
Hardwood	176,616	1,094,231	896,289	10,020	2,178,989	54.0
METAL MINING PRODUCTION (thousands of tonnes)						
Iron Ore		5,421	17,842	25,686	48,949	98.8
Copper	55,983	225,838	85,153	-	366,974	53.1
Zinc	39,541	246,027	53,200	-	338,768	37.2
Gold	1.3	18.2	22.1	-	41.6	80.0
FOSSIL FUEL CONSUMPTION (terajoules) + +						
Mining Industry	1,477	15,191	12,024	17,162	45,854	38.6
Manufacturing	23,789-24,288	86,571	44,851	0-99	155,809	15.8
Thermal Generating Stations	5,569	8,984	467	-	15,020	1.8

SOURCE: Statistics Canada 1986

* Based on summation of the following ecozones: Hudson Bay Plain, Boreal Plain, Boreal Shield and Taiga Shield.

** Population has been summarized by drainage basin, not ecozones.

+ Productive Forestland is stocked and nonstocked inventoried land capable of producing a merchantable stand within a reasonable length of time.

+ + Includes data for southwestern Manitoba (Prairie Ecozone).

extensively modified by human activities. In the area southwest of Lake Manitoba, wetland cover has declined from 13.2 percent to less than 4 percent since 1928 due primarily to agricultural conversion (Rakowski and Chabot 1983). In the vicinity of Winnipeg, over 75 percent of the pre-settlement wetlands have been lost as a result of conversion to agricultural use (Kessel-Taylor 1984).

2.2.3 FORESTRY

Trees are a source of oxygen and a sink for carbon which accumulates within the biomass of the forest. Forestry activities affect the air chemistry of the study area by: 1) logging which may result in short term reductions in the uptake of carbon dioxide; 2) forest regeneration which results in longer term increases in carbon dioxide removal from the atmosphere; and 3) burning of wood and fossil fuels which increases the flux of carbon into the atmosphere.

Wood provides a common source of heating fuel for homes in northern regions and logged areas are commonly burned in preparation for regeneration. Fossil fuels are burned to supply power to pulp and paper mills and to meet transportation requirements.

Table 2.2.1 lists the area of productive forest land and the associated volume of hardwood and softwood species. Hardwoods are proportionately more abundant in southern portions of the study area (see Section 2.8) and it is likely that a significant portion of the volume shown in Table 2.2.1 occurs south of the study area.

The primary use of softwood trees is for pulp and paper production and saw timber for rough framing material. There are 15 pulp and paper mills within the study area 13 of which are in Ontario. The largest concentration of mills is in northwestern Ontario with 7 located on the north shore of Lake Superior (including 4 mills in Thunder Bay). The mill locations are shown on Map 2.2.2.

2.2.4 MINING

The mining of fossil fuels, minerals and metals does not directly affect the Northern Wetlands Study. They are primarily of concern due to the burning of fossil fuels for support activities and through the smelting of ferrous and non-ferrous metals.

Table 2.2.1 shows the 1981 production of the four dominant metals mined in the Northern Wetlands Study area. The location of the mines and the primary metal produced at each is shown in Map 2.2.2. Iron ore deposits are extensive within the study area, particularly in Labrador and eastern Québec.

There are no known reserves of oil, natural gas nor high-grade coal within the Northern Wetlands Study area. The geology of the area to the south of Hudson Bay and west of James Bay (Hudson Bay Lowland) is similar to southwestern Ontario where large deposits of natural gas have been found. Seismic and drilling operations have been carried out in the deeper portions of the geological strata but commercial deposits of oil or gas have not been found (Oilweek 1972, Sanford and Norris 1975).

Lignite, a poor quality form of coal intermediate between peat and sub-bituminous coal, occurs southwest of Moosonee, Ontario (Map 2.2.2). This deposit is believed to contain 189,000,000 tons average recoverable medium-grade lignite (Onakawana Development Ltd. 1973). The lignite is located in an area of poor accessibility and the availability of low cost, higher quality coals from western Canada have prevented development of the Onakawana deposit. Feasibility studies have shown that the lignite would only be economical to extract if a thermal power station was built in close proximity (Onakawana Development Ltd 1973).

Peat is mined for use as a fuel and as a soil conditioner in agricultural and horticultural applications. Although more common in Scandinavia, the British Isles and the Soviet Union, the harvesting of peat reserves in Canada has been increasing in recent years. Canadian peat production totals approximately 500,000 tonnes per year (Rubec *et al.* 1988). The 1983 production for Québec, Ontario and Manitoba was 238,000 tonnes, 4,000 tonnes and 54,000 tonnes, respectively (Statistics Canada 1983 as cited in Rubec *et al.* 1988). Nearly all of the Ontario and Québec production is outside of the Northern Wetlands Study area close to southern markets.

2.2.5 TRANSPORTATION

Most communities within the Northern Wetlands Study area are single industry communities established on the basis of forestry, mining or hydro-electric development. They are serviced primarily by north-south corridors which form fairly direct routes to major shipping or manufacturing centres located south of the study area.

Airports service most of the communities within the study area (Map 2.2.1). International airports serve to connect passengers with the air transportation network outside of Canada and also carry the majority of the interprovincial travel (Energy Mines and Resources 1974). Regional airports provide local, regularly scheduled services as well as direct access to international airports. Regional airports are located at Churchill, Thompson, Flin Flon, Lynn Lake and The Pas, Manitoba; Dryden, Thunder Bay, Moosonee and Timmins, Ontario; Rouyn and Val d'Or, Québec; and Goose Bay, Labrador. There are approximately 40 local airports. They do not have commercial facilities but have regularly scheduled passenger services and periodic freight charters.

2.2.6 ENERGY GENERATION AND CONSUMPTION

The location of thermal generating stations and hydro-electric generating stations within the Northern Wetlands Study area are shown in Map 2.2.2. Table 2.2.1 lists the consumption of fossil fuels for the mining and manufacturing industries and for thermal electric power generation. The data for manufacturing includes the pulp and paper sector and includes all aspects of their operations including paper production, transportation and space heating (Statistics Canada 1986). Major reservoirs and their associated generating capacity are shown in Table 2.2.2.

There are approximately 66 reservoirs for hydro-electric power generation within the study area (Statistics Canada 1986). Most are fairly small with less than 60 km^2 of land flooded. The largest reservoirs (i.e., greater than 60 km^2) have all been built since 1960. These include 2 in Labrador, 5 in Québec and 6 in Manitoba (Table 2.2.2). Recent public announcements indicate that additional large hydro-generating stations are planned for the Nelson River (Manitoba) and Baie James (Québec) in the near future.

There are 56 thermal electric generating stations with a capacity of 100 kilowatts or greater (Statistics Canada 1986). The largest thermal generating stations generate between 50,000 and 500,000 kilowatts of energy. These large stations are located at Winnipeg (2 stations), Atikokan and Thunder Bay, Ontario (2 stations), and Rouyn, Québec.

The consumption of fossil fuels produces gaseous emissions which contribute to the greenhouse effect. The primary gases emitted include nitrous oxide, carbon monoxide and carbon dioxide. The total fossil fuel energy consumption within the study area in 1981 was 216,683 terajoules (Table 2.2.1).

The 1978 annual emissions of sulphur dioxide, nitrogen oxides, hydrocarbons and carbon monoxide for Canada are reported on the basis of 127 by 127 km grid cells by Statistics Canada (1986). Sources included in this inventory are major power plants and municipal incinerators as well as an estimate for small industrial sources (such as sawmills), residential fuel combustion and transportation sources (Statistics Canada 1986).

TABLE 2.2.2

Major reservoirs within the Northern Wetlands Study area, 1984*.

LOCATION	RESERVOIR	PROJECT	RIVERS DAMMED	TOTAL SURFACE AREA (km^2)	LAND AREA FLOODED (km^2)	GENERATING CAPACITY (megawatts)
Labrador	Ossokmanuan	Twin Falls	Unknown	950	238	234
	Smallwood	Churchill Falls	Churchill	5,696	2,848	5,225
Quebec	LG2	LG2	La Grande	2,836	N/A	5,328
	Opinaca	LG2	Opinaca, Eastmain	1,036	738	as above
	LG3	LG3	La Grande	1,865	N/A	1,920
	LG4	LG4	La Grande	N/A	N/A	2,637
	Caniapiscau	LG4	Caniapiscau	4,299	N/A	as above
Manitoba	Kelsey	Kelsey	Nelson	706	124	236
	Stevens Lake	Kettle Rapids	Nelson	337	236	1,224
	S. Indian Lake	Nelson River-Missi Falls	Churchill	2,391	414	980
	Notigi	Nelson River-Notigi Central	Rat, Churchill	584	431	as above
	West Nelson Channel	Jenpeg	Nelson	N/A	186	
	Cedar Lake	Grand Rapids	Saskatchewan	3,493	1,372	437

SOURCE: Statistics Canada 1986

* Major reservoirs are those in which more than 60 km^2 of land was flooded. Land area flooded excludes the area of former open water.

Within the study area the largest emissions of nitrogen oxides range between 10,000 and 170,000 tonnes and occur in the grid cells representing Winnipeg and Thunder Bay. In three grid cells surrounding Winnipeg and three cells in the Timmins—Rouyn region of Ontario and Québec, emissions are in the range of 2,500 to 9,999 tonnes.

Carbon monoxide (CO) emissions are highest from Winnipeg (100,000 to 930,000 tonnes—1 grid cell) followed by Thunder Bay and Timmins—Rouyn (20,000 to 99,999 tonnes—total of 3 grid cells).

Hydrocarbon emissions are generally less than 50,000 tonnes throughout the study area with the largest emissions from Winnipeg and Thunder Bay (5,000 to 49,999 tonnes—total of 3 grid cells). Wawa, Ontario is also a major source of hydrocarbon gases.

2.2.7 REFERENCES

Energy, Mines and Resources. 1974. *The National Atlas of Canada*. 4th Edition, Macmillan Co. of Canada, Toronto.

Energy, Mines and Resources. 1985. *The National Atlas of Canada*. 5th Edition, Energy, Mines and Resources Canada, Ottawa, Ontario.

Kessel-Taylor, I. 1984. The application of the Canada Land Data System for quantitative analysis of land use dynamics on wetlands for twenty-three urban centred regions in Canada. CLDS Rept. No. R003200, Lands Directorate, Environment Canada, Ottawa, Ontario.

Oilweek. 1972. Major push planned by oil-hunters for next year in Hudson Bay Region. *Oilweek*, 23(42): 60-62.

Onakawana Development Ltd. 1973. Onakawana Project: lignite mine and power plant development, engineering feasibility study and economic analysis. Ontario Ministry Nat. Res., Report 5366-4-73: 2 volumes.

Rakowski, P.W. and B.P. Chabot. 1983. Changes in land use in the Minnedosa District of southwestern Manitoba: an update of the Keil-Hawkins transect. Unpublished Manuscript, Canadian Wildlife Service, Environment Canada, Winnipeg, Manitoba.

Rubec, C.D.A., P. Lynch-Stewart, G.M. Wickware and I. Kessel-Taylor. 1988. Wetland Utilization in Canada. Chapter 10. *In. Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 378-412.

Sanford, B.V. and A.W. Norris. 1975. Devonian stratigraphy of the Hudson Platform. Geol. Surv. Can., Memoir 379: 2 parts.

Statistics Canada. 1983. General review of the mineral industries. Catalogue 26-201, Supply and Services Canada, Ottawa, Ontario.

Statistics Canada. 1986. Human Activity and the Environment, A Statistical Compendium. Supply and Services Canada, Cat. No. 11-509E: 373p.

2.3 CLIMATE

2.3.1 SOLAR RADIATION

Radiant energy from the sun is fundamental to life-sustaining processes at the Earth's surface and surface exchange processes. For example, Hare and Ritchie (1972) attempted to establish empirical relationships between the radiation climate and the Boreal forest structure and productivity.

Incoming global solar radiation is composed of "direct" radiation from the sun and "diffuse" radiation reflected or scattered by clouds and atmospheric particles. Short-wave radiation includes wavelengths from 0.3 to 3.0 microns. A large percentage of the radiant energy is reflected back to space by the Earth's surface. The percent reflected from the surface is a function of snow and ice cover, vegetation, soil moisture, surface roughness, slope and colour. As indicated in Table 2.3.1, there is a large range in albedo values from over 80 percent for fresh snow to 8 percent for lakes (Wilson 1975). The usefulness of short-wave radiation to plant photosynthesis is, in part, dependent upon its spectral composition; plants require nearly visible light (Robertson 1966). Diffuse solar radiation has a greater proportion of the necessary light than direct solar radiation. In the Boreal and Arctic, the diffuse component of global solar radiation is higher due to the long path of solar radiation (Hare and Ritchie 1972).

TABLE 2.3.1

Fraction of solar radiation reflected (albedo) by various surfaces.

TYPE OF SURFACE	ALBEDO Summer	ALBEDO Winter*
Open Sites		
freshly fallen snow	—	over 0.8
old snow	—	0.4 to 0.7
Vegetation Types		
tundra	0.2	0.8
open woodland	0.2	0.6
coniferous forest	0.1	0.3 to 0.4
grassland, growing crops	0.2	0.4 to 0.6
Other Surfaces		
lakes	≈0.08	0.5 to >0.8

SOURCE: Hare and Thomas 1979

* Snow-covered assumed; values also apply for spring time prior to snow melt.

The Earth loses heat to space by terrestrial long-wave radiation. Long-wave radiation is emitted by the earth's surface, clouds, water vapour, carbon dioxide and particles in the atmosphere. Long-wave radiative exchanges, at wavelengths greater than 3.0 microns, occur continuously and usually cool the Earth's surface. The cooling process is most effective at night and during winter.

Net all-wave radiation is the balance between short- and long-wave radiation gains and losses. The surface radiation balance can be expressed as:

$$Q^{*} = K{\downarrow}(1-\alpha) - L{\uparrow} + L{\downarrow} \qquad (1)$$

where: Q^{*} = net all-wave radiation;
$K{\downarrow}$ = global solar radiation (direct and diffuse components);
α = albedo is the ratio of reflected to incoming solar radiation ($K{\downarrow}/K{\uparrow}$);
$L{\uparrow}$ = long-wave terrestrial radiation, emitted by the surface;
$L{\downarrow}$ = long-wave atmospheric radiation, received by the surface.

On an annual basis, all Canadian land areas have a positive net radiation balance. It is negative from November to January and positive only from May to August (Fisheries and Environment Canada 1978). Surplus radiative energy is available to heat the atmosphere (H), melt snow and ice (M), evaporate water (LE), heat the soil (G), and provide energy for photosynthesis of plants (P). The heat balance may be described by the equation:

$$Q^{*} = H + LE + G + P + M \qquad (2)$$

Map 2.3.1A presents the spatial distribution of annual global solar radiation and annual net radiation (Titus and Truhlar 1969, Hay 1970). Minimum radiation values occur in the north and maximum values in the south. At the same latitude, solar radiation values are higher in the west than the east. This pattern reflects regional influences such as synoptic systems, cloud, temperature, atmospheric water vapour, air pollution and proximity to water.

Incoming global solar radiation varies seasonally according to solar angle, day length and cloudiness. For example, in winter, latitudinal variation in incoming global solar radiation is quite pronounced. Low solar elevation and short days result in low radiation along the southern border of the Northern Wetland Study region; incoming radiation falls to zero in the polar night region of the high Arctic. In summer, the low solar elevations in the north are compensated by longer days. Consequently, total daily solar radiation can be relatively high. The pronounced latitudinal gradient of the winter is lessened (Fisheries and Environment Canada 1978).

The net radiation isolines reflect the complex interaction between and distribution of the component short- and long-wave fluxes. Seasonal variation is large. Canadian land surfaces, on average, have a negative radiation balance from late November to mid February when long-wave cooling of the surface outweighs solar heating. In southern areas, net radiation becomes positive in February or March. This leads to snowmelt; a decrease in the albedo; and an increase in net radiation. Latitudinal gradients of net radiation are strongest at this time due to the contrast between snow-covered and snow-free areas. Net radiation has a positive balance from May to August. June is usually the month with the strongest radiative heating while a rapid downturn occurs in August. December experiences the strongest cooling. The air temperature regime lags behind this cycle due to thermal storage in the soil, water bodies and the oceans. Lakes and wetlands accentuate the seasonal lag (Hare and Hay 1979).

The amount and persistence of cloud cover are the next most important influences on the radiation balance. Clouds deplete the downward flux of shortwave radiation through absorption, reflection and backscattering. The amount of radiation lost is a function of cloud amount, type, opacity, and thickness. Cloud layers diffuse incoming radiation while blocking out the direct solar radiation. The proportion of short-wave radiation components changes; the amount of direct radiation becomes smaller while the diffuse radiation becomes larger.

Since cloudiness has an important influence on fluxes, Map 2.3.1B presents graphs of the monthly percent frequency of cloud conditions from clear to overcast for 11 stations in the region. In order to illustrate the diurnal changes in cloud conditions, the mean hourly July frequency of 0 to 2 tenths clouds (clear) and 8 to 10 tenths clouds (overcast) are provided on Map 2.3.1C.

2.3.2 TEMPERATURE

Temperature controls numerous biophysical processes including: the rate of biological productivity; the limits of plant distribution; in combination with the radiation balance and humidity, determines heat and water vapour fluxes; and the soil temperature regime and thereby permafrost development. Mean January and July daily air temperatures for the period 1951 to 1980 are reproduced in Maps 2.3.2A and 2.3.2B. Monthly mean temperature statistics for 11 stations within the study area are presented in Map 2.3.2C.

The distribution of temperature is controlled by latitude, topography, surface characteristics and proximity to large water bodies. The diurnal and annual solar cycles are a function of latitude. These cycles determine the intensity and duration of solar radiation. This influences temperature. The latitudinal effects are shown on the maps by a decrease in temperature from south to north.

Irregularities in topography and surface characteristics and the influence of water bodies contribute to regional climatic variability and are reflected by deviations from the latitudinal influence. For example, Hudson Bay and the Atlantic Ocean exert a major moderating influence during open water season. Coastal sites, generally, are warmer in winter and cooler in summer as compared to inland locations which are not influenced by lake or marine effects. The condition of the land surface, whether it is dry or wet, soil covered or rocky, influences the temperature regime. Temperature, generally, decreases with elevation and, hence, isotherms tend to parallel topographic contours.

2.3.2.1 JANUARY

The east coast of Hudson Bay is warmer than other areas at the same latitude in the region due to the delayed freezing of James and Hudson Bays (Danielson 1969). The relatively warm, open water heats prevailing northwest winds before they reach the Québec shore. However, by mid to late January, most of the surface of Hudson Bay is snow and ice covered. Then the bay provides a long fetch for cold air masses to intrude southward uninterrupted by any topographical barriers. The Atlantic Ocean exerts a similar moderating influence on temperature along the east coast of Labrador.

The Labrador-Ungava Plateau has regionally colder temperatures (note the southward dip of the -22.5°C isotherm). The land rises in elevation southward and this offsets the latitudinal influence.

2.3.2.2 JULY

The Hudson Bay and Atlantic coastal regions experience low mean July temperatures for their latitude in spite of high values of summer net radiation. Hudson Bay remains frozen through June. The melting ice pack keeps the surface water temperatures near freezing. The cool water affects the summer climate by reducing temperatures as shown by the slope of the isotherms south of James and Hudson Bays. Although the prevailing winds along the Atlantic are offshore, onshore winds can blow during spring and summer. Winds that pass over the cold Labrador current and ice pack bring cold temperatures, fog and low cloud to the coast of Labrador.

2.3.3 GROWING DEGREE-DAYS

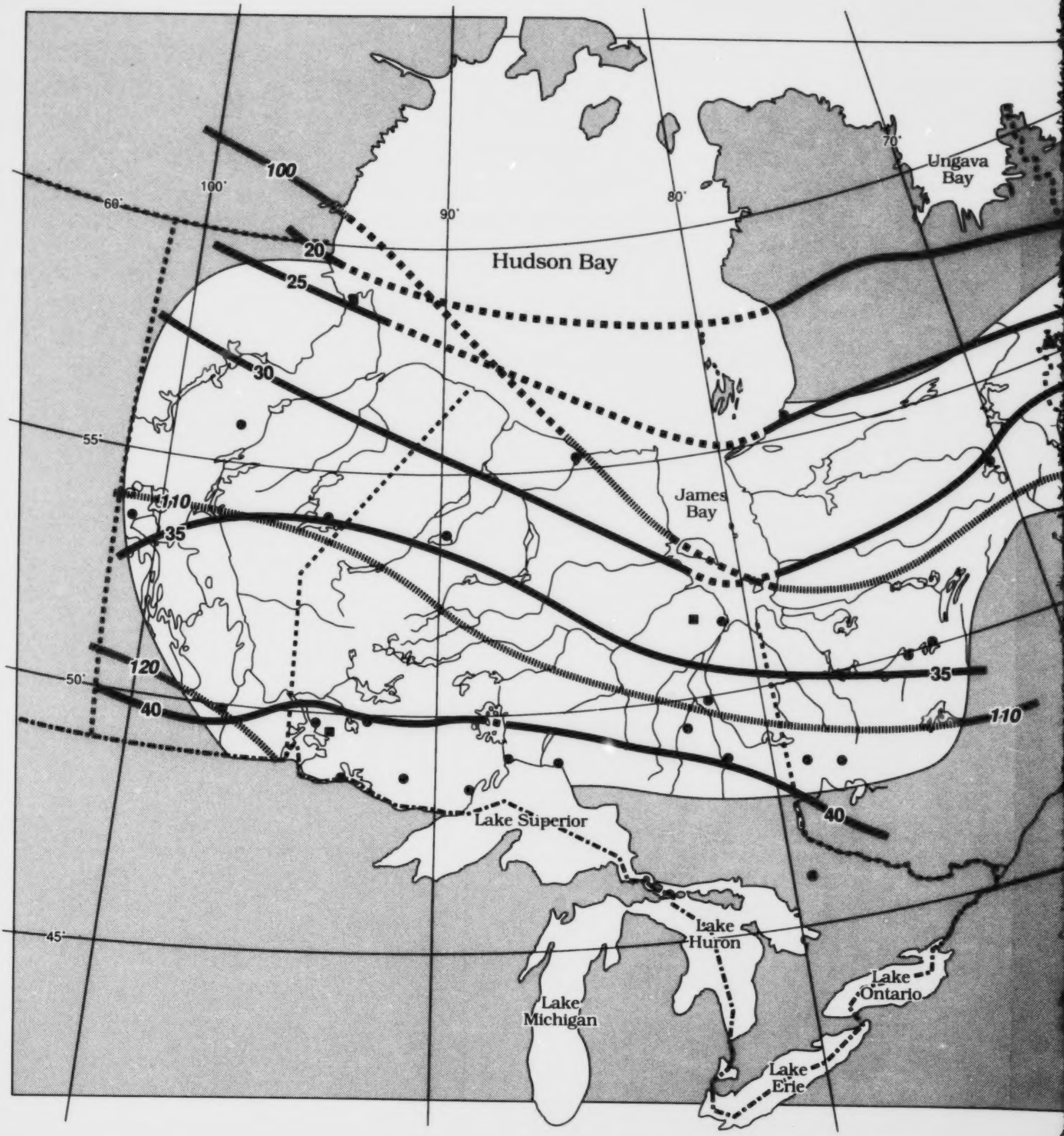
The length and warmth of the growing season are important for plant productivity. Growing degree-days, based on the threshold temperature of 5°C, have been used as an indicator of climate and rate of plant growth and development. The index is expressed as a sum of positive departures of mean daily temperature from 5°C.

Annual total growing degree-days are presented in Map 2.3.3. Most of the data are representative of a 30-year average (1951 to 1980).

The index is based on the assumption that plant growth begins or becomes significant as temperature rises above 5°C and plant growth increases linearly as temperature exceeds this threshold. However, the critical temperature varies for each plant species as well as throughout the life cycle of a plant. Factors such as photoperiod have not been incorporated into the index (Chang 1970, Monteith 1965).

The growing season can be curtailed by late spring and/or early fall frost, when the temperature falls to 0°C or less. Cold northerly winds can produce a widespread freeze; radiational cooling on clear, still nights causes localized frosts. In radiational frosts, topography and soil type cause local variation in vulnerability. Cold, heavier air drains into depressions from slopes. Heat loss is partly a function of soil texture, increasing from sands to clays and loams. The greatest heat loss is from peat materials. The moderating influence of water on temperature reduces frost susceptibility. James Bay, for example, causes the extension of the frost-free period in the fall. The wetlands of the Hudson Bay Lowland, extending almost 170 km inland, also prolong the frost-free season (Chapman and Thomas 1968).

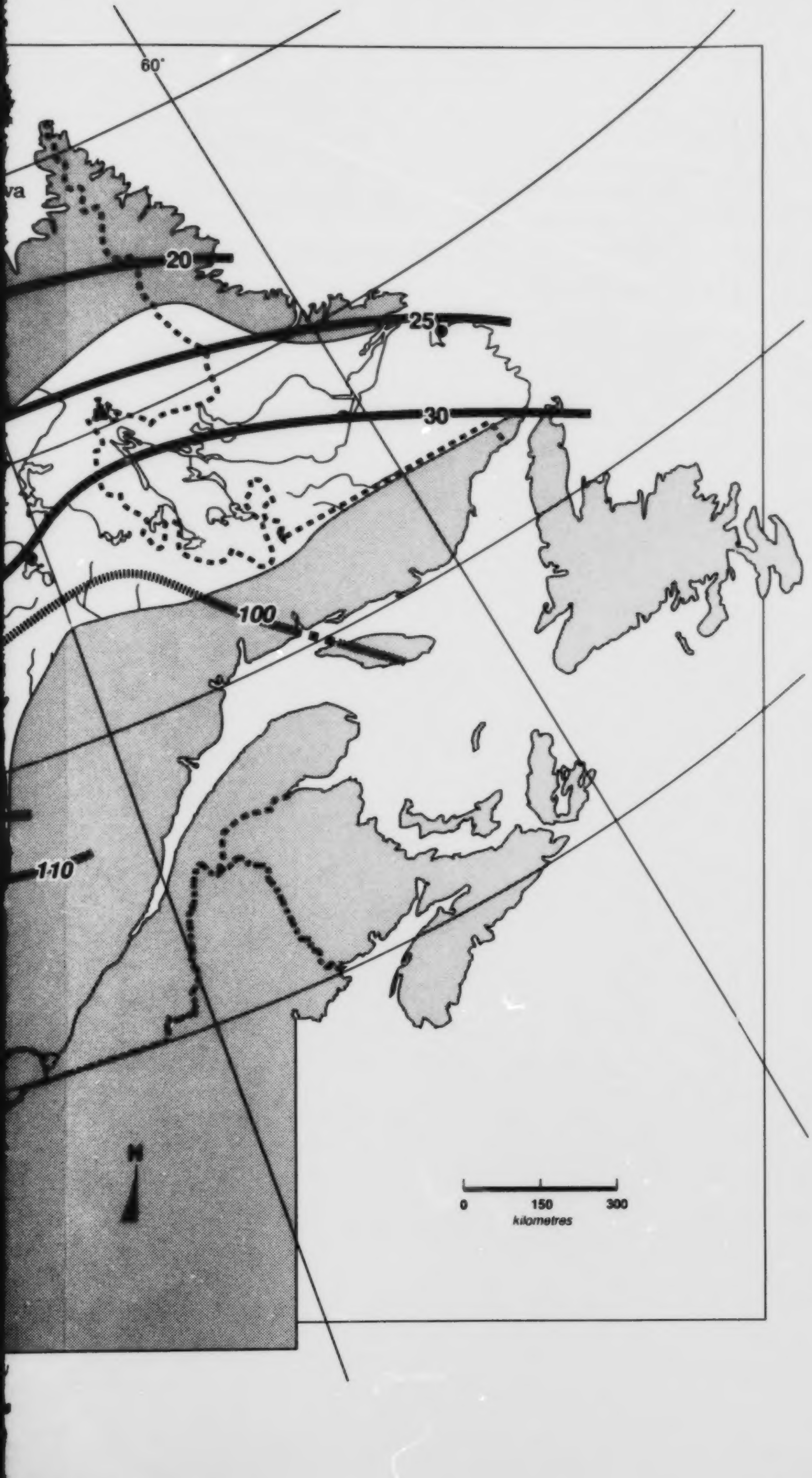
Climatic data on growing season characteristics for 11 stations within the Northern Wetlands Study area are presented in Table 2.3.2. All stations, except Thompson, Manitoba (14 years) and Chibougamau, Québec (17 years), represent the full 30-year period of record from 1951 to 1980. Freeze-free days are the annual total number of days where the mean daily temperature is above 0°C. The growing season (in days) commences when the mean daily temperature is greater than or equal to 5°C for 5 consecutive days and ends when the minimum daily temperature is less than or equal to -2°C.


100
100°
60°
90°
80°
70°
Ungava Bay
20
Hudson Bay
25
30
55°
James Bay
110
35
35
120
50°
110
40
Lake Superior
40
Lake Huron
45°
Lake Ontario
Lake Michigan
Lake Erie

map 2.3.1A

NORTHERN WETLANDS STUDY AREA

Annual global solar radiation and mean annual net radiation



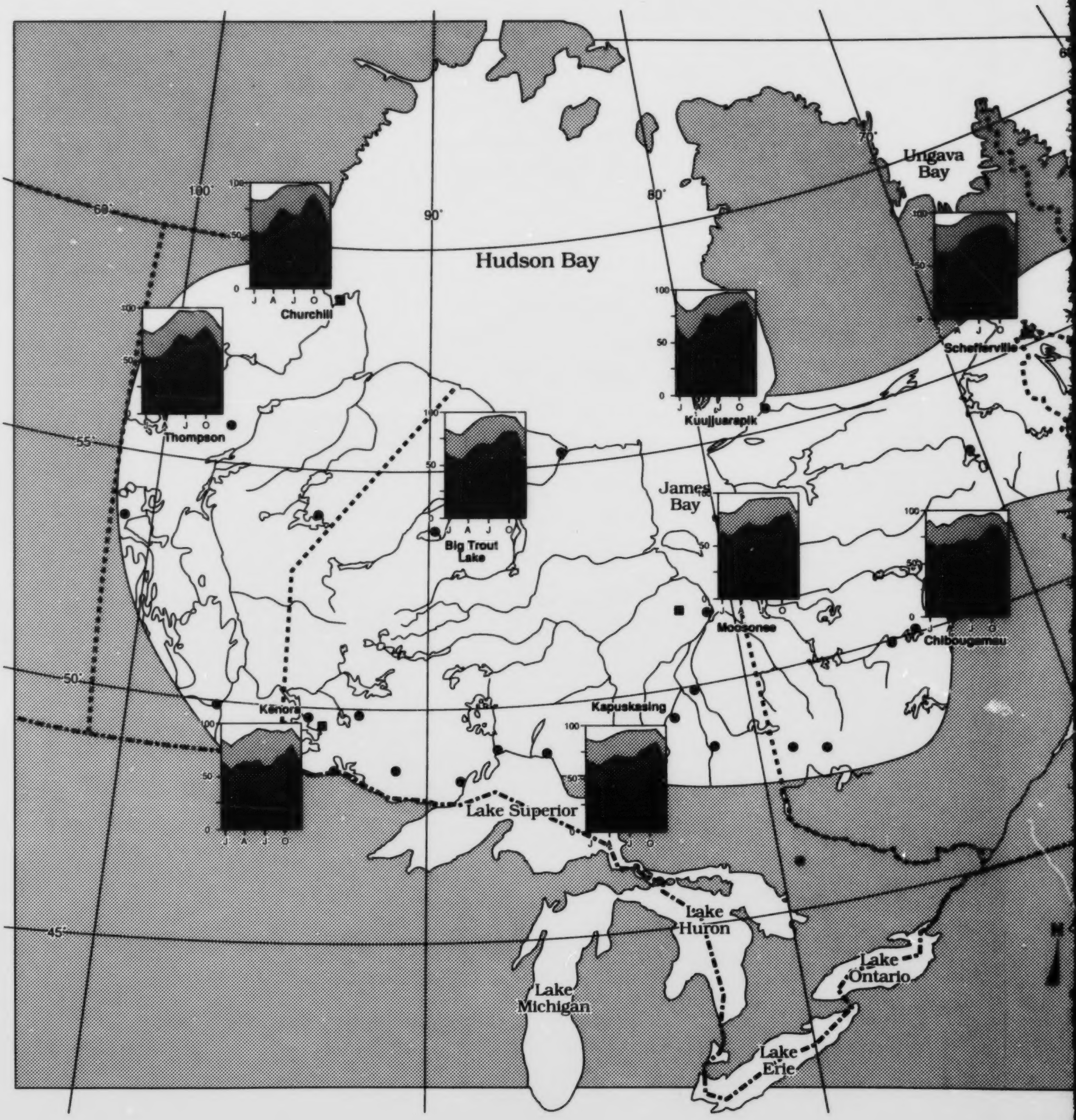
▥ annual global solar radiation (kilocalories/cm^2)

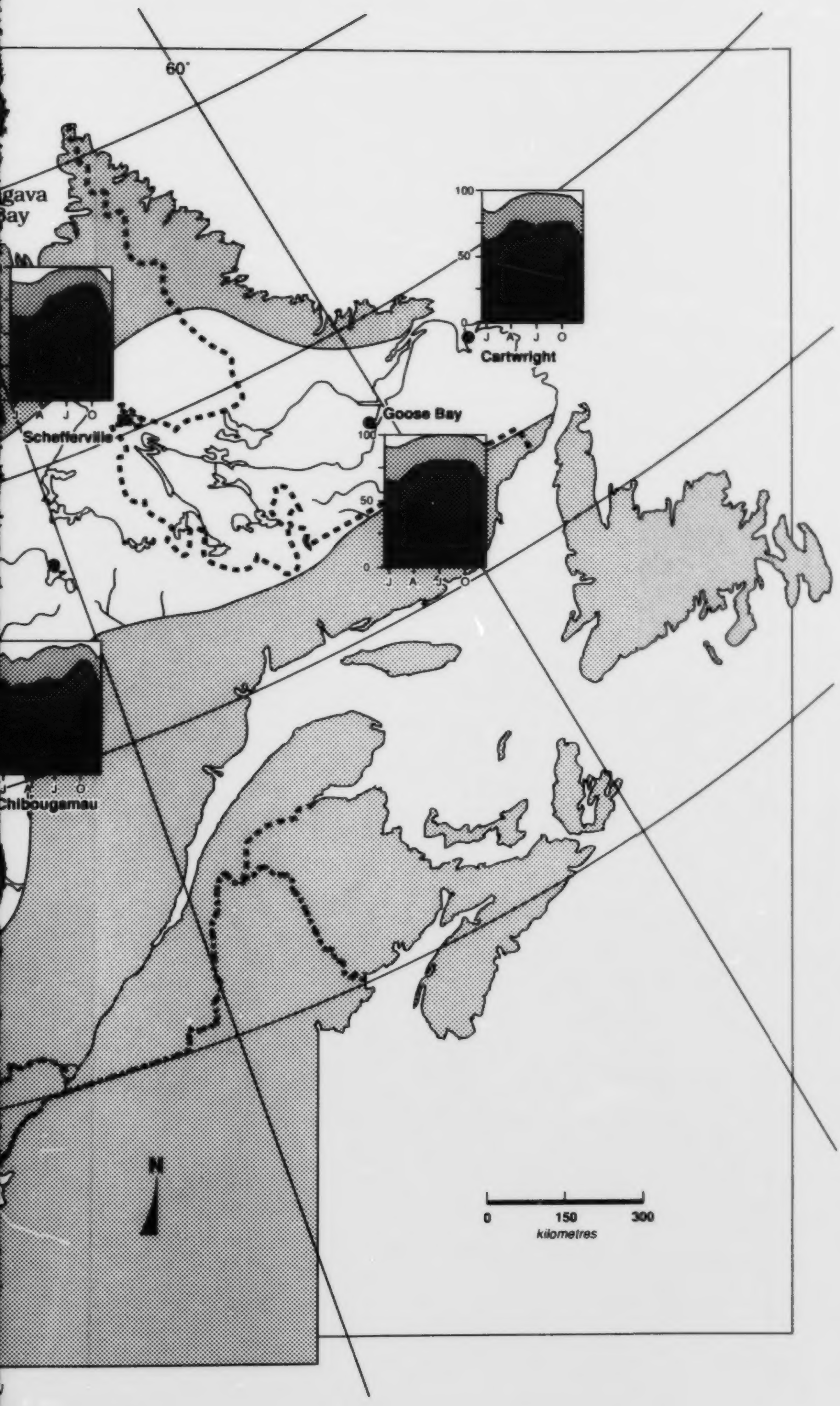
▬ mean annual net radiation (kilocalories/cm^2)

Note: dotted lines indicate approximate values

Source:
Hydrological Atlas of Canada, 1:20 m,
(Fisheries and Environment Canada, 1978)

Projection: polar stereographic

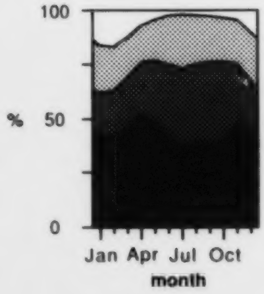

Hudson Bay
James Bay
Ungava Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
Churchill
Thompson
Big Trout Lake
Kuujjuarapik
Schefferville
Moosonee
Chibougamau
Kapuskasing
Kenora
100°
90°
80°
70°
60°
55°
50°
45°
0
50
100
J
A
J
O



map 2.3.1B

NORTHERN WETLANDS STUDY AREA

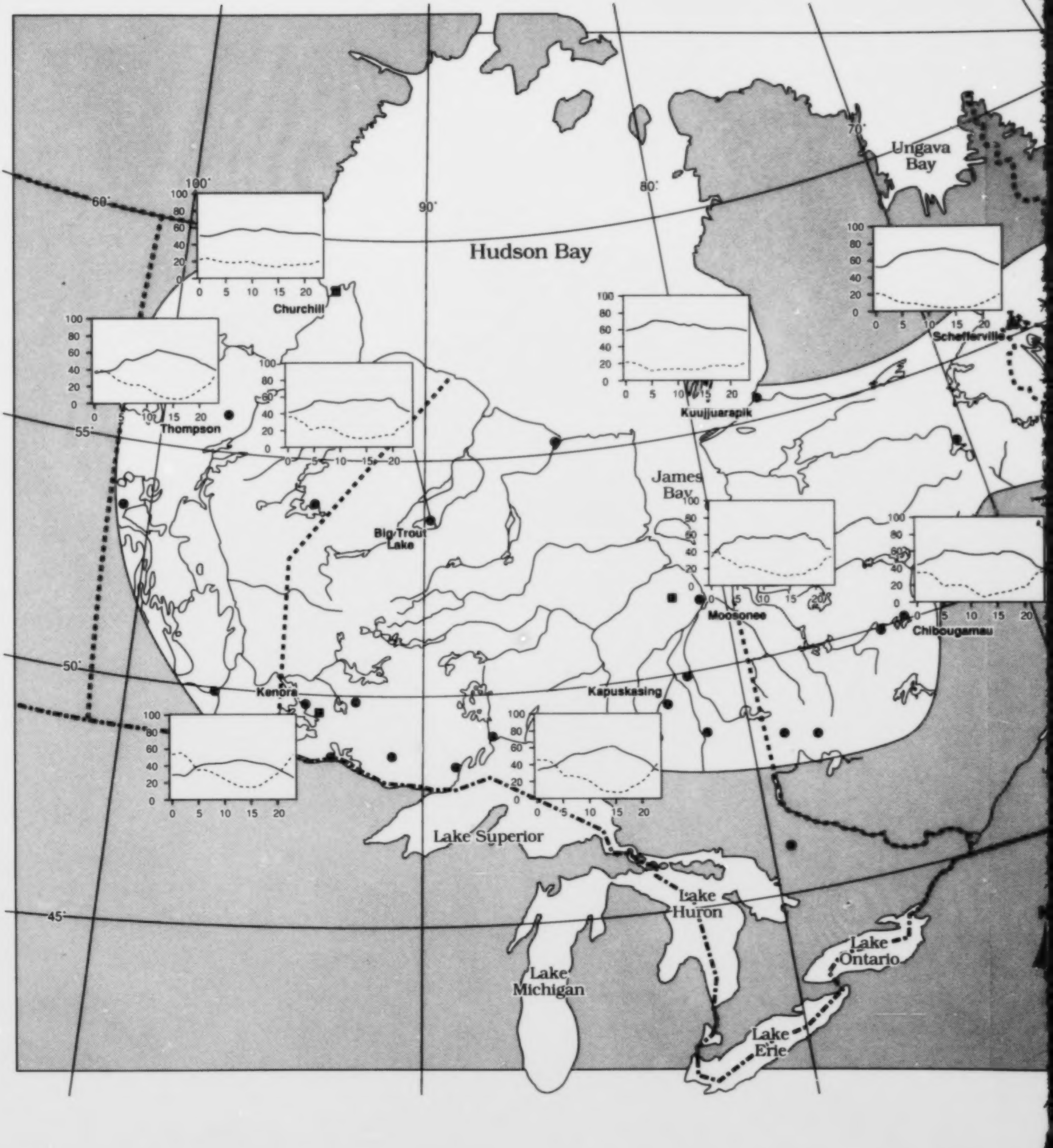
Monthly percent frequency of cloud amounts at selected climate stations



- ☐ clear: 0 10ths of cloud
- ▨ scattered: 1 - 5 10ths of cloud
- ▩ broken: 6 - 9 10ths of cloud
- ■ overcast: 10 10ths of cloud

Source:
Canadian Climate Centre,
National Archive

Projection: polar stereographic

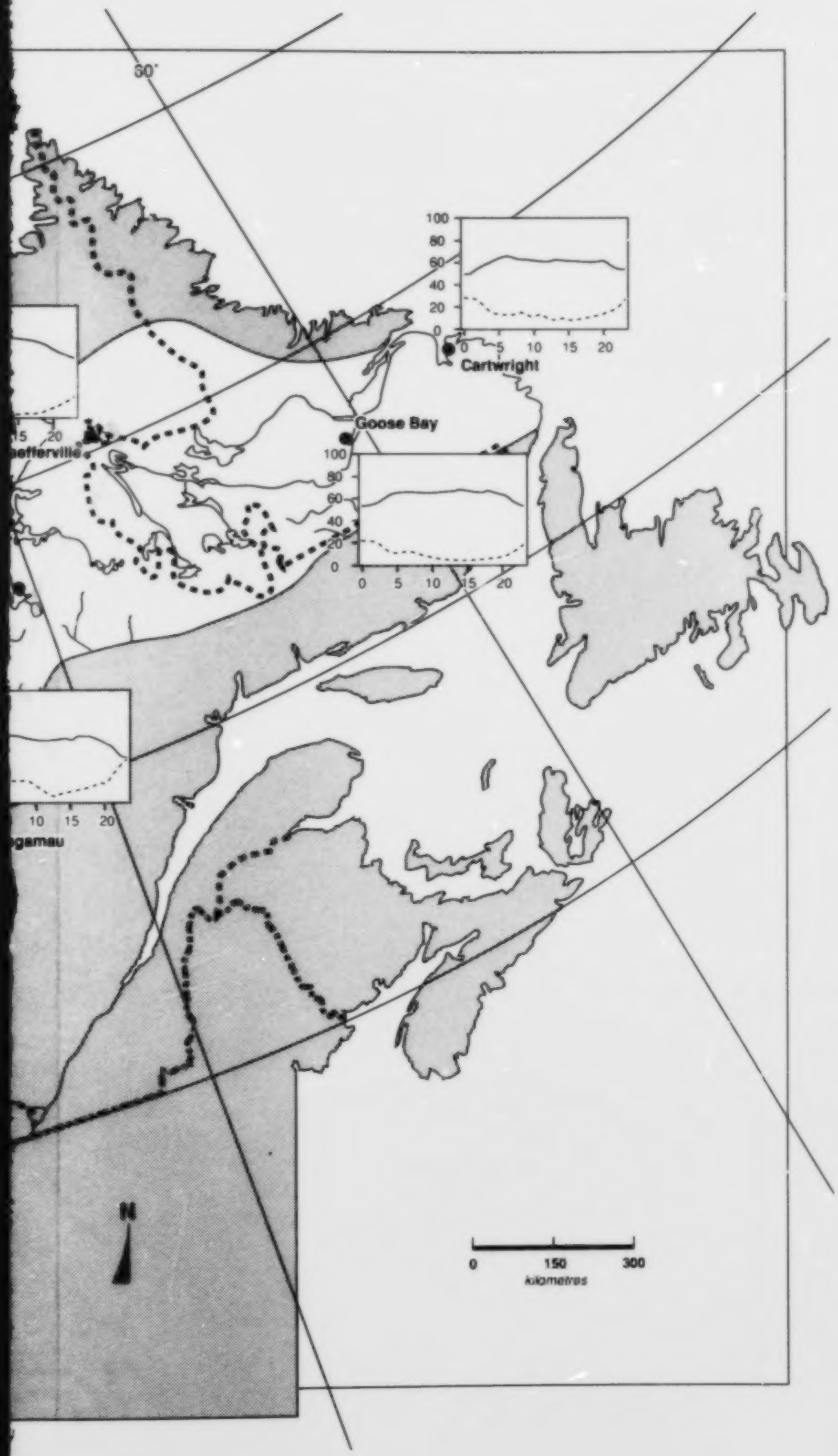


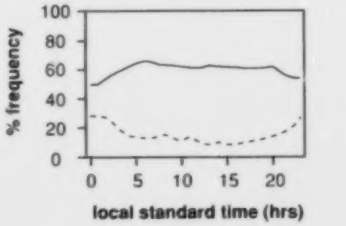
Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°
Churchill
Thompson
Big Trout Lake
Kuujjuarapik
Schefferville
Moosonee
Chibougamau
Kenora
Kapuskasing
100
80
60
40
20
0
0
5
10
15
20

map 2.3.1C

NORTHERN WETLANDS STUDY AREA

July hourly percent frequency of clear sky and overcast conditions



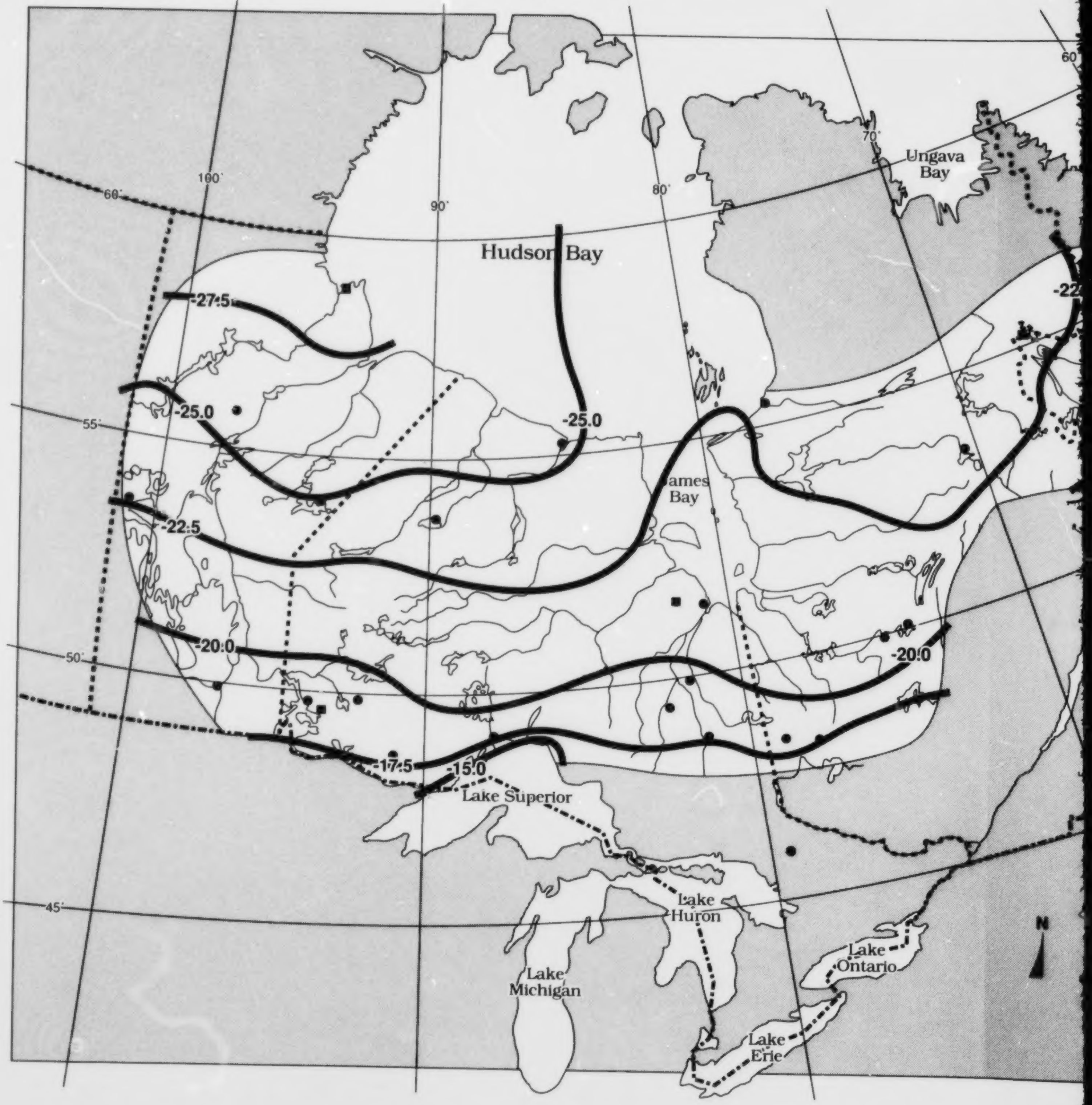


8-10 10ths cloud cover (overcast)

0-2 10ths cloud cover (clear)

Source:
Canadian Climate Centre,
National Archive

Projection: polar stereographic

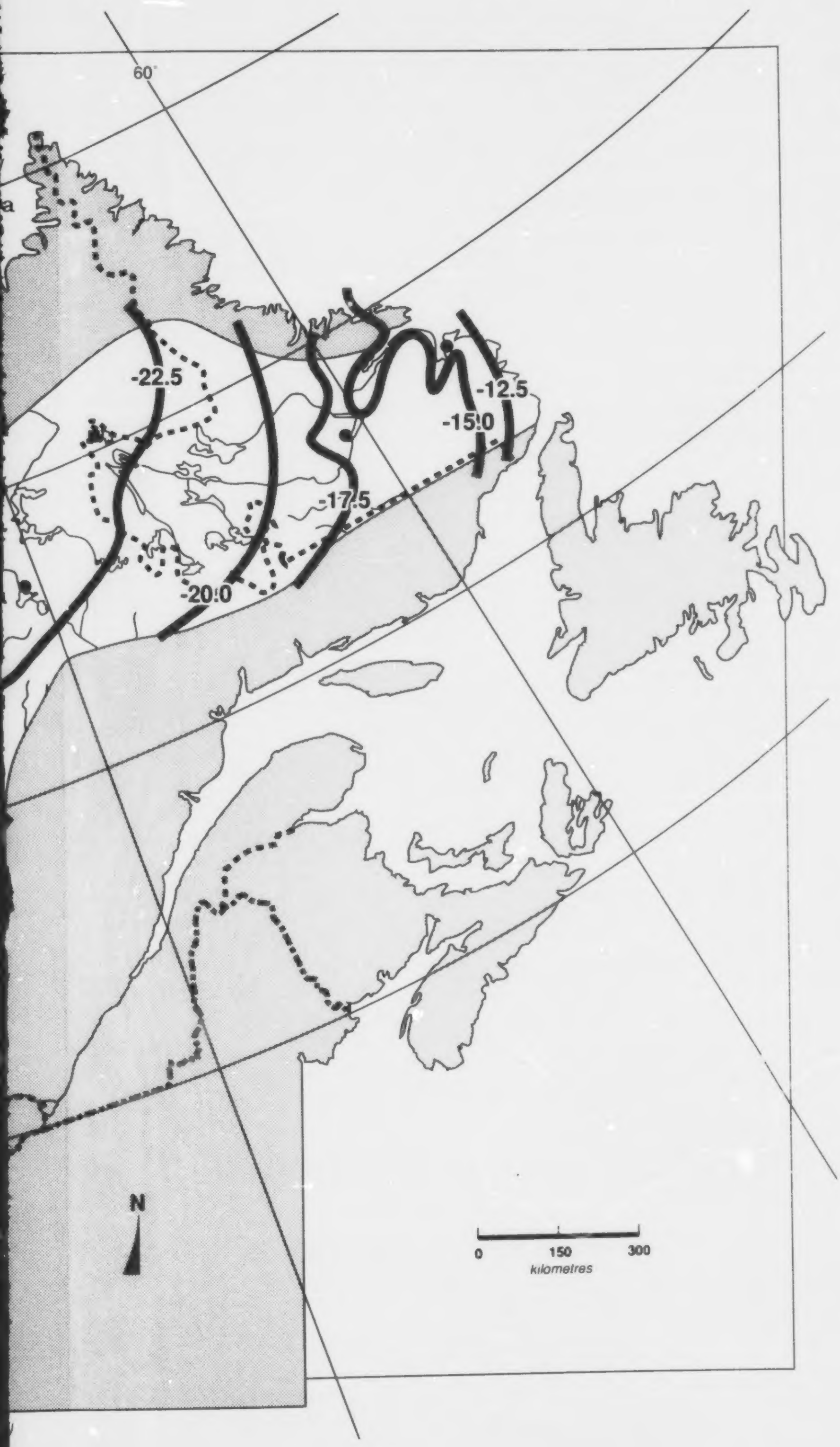


60°
100°
90°
80°
70°
60
Ungava
Bay
Hudson Bay
-27.5
-25.0
-25.0
-22
55°
James
Bay
-22.5
-20.0
-20.0
50°
-17.5
-15.0
Lake Superior
45°
Lake
Huron
Lake
Ontario
Lake
Michigan
Lake
Erie
N

map 2.3.2A

NORTHERN WETLANDS STUDY AREA

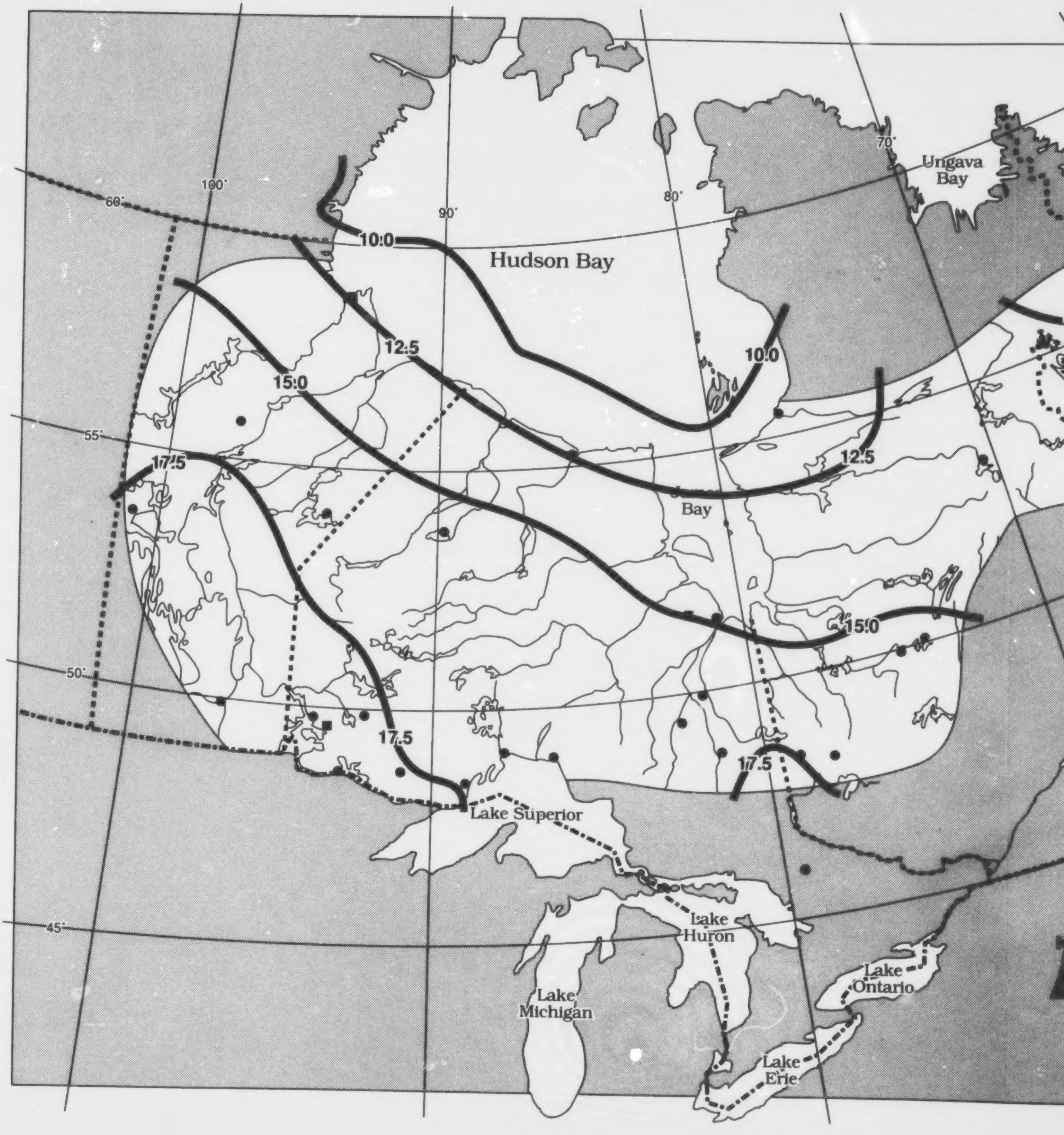
Mean daily temperature - January



▬ mean daily temperature (°C) - January

Source
Climatic Atlas Canada, 1:12.5 m
(Atmospheric Environment Service, 1984)

Projection: polar stereographic

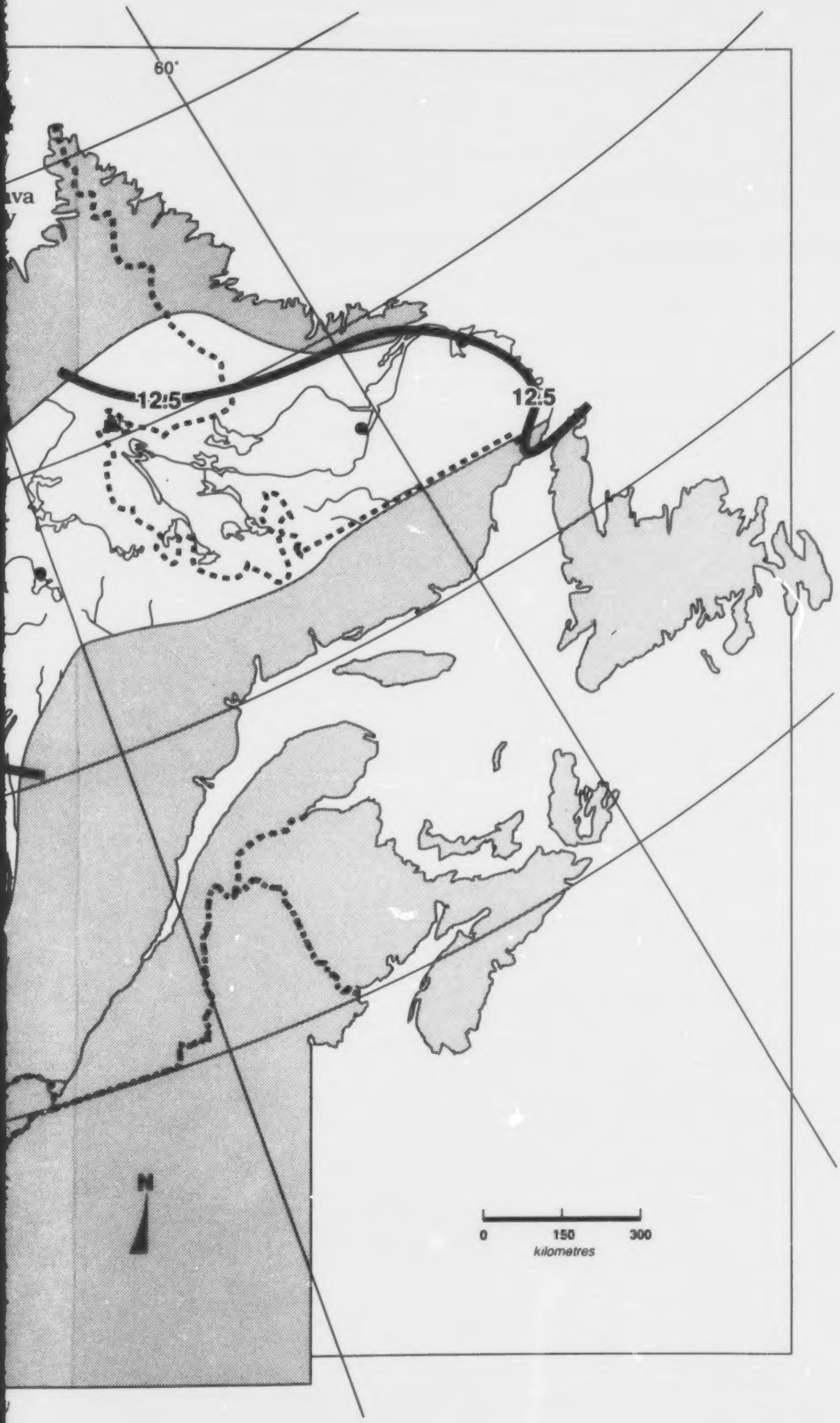


60°
100°
90°
80°
70°
Ungava Bay
Hudson Bay
10.0
12.5
15.0
17.5
10.0
12.5
55°
James Bay
15.0
50°
17.5
17.5
Lake Superior
45°
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie

map 2.3.2B

NORTHERN WETLANDS STUDY AREA

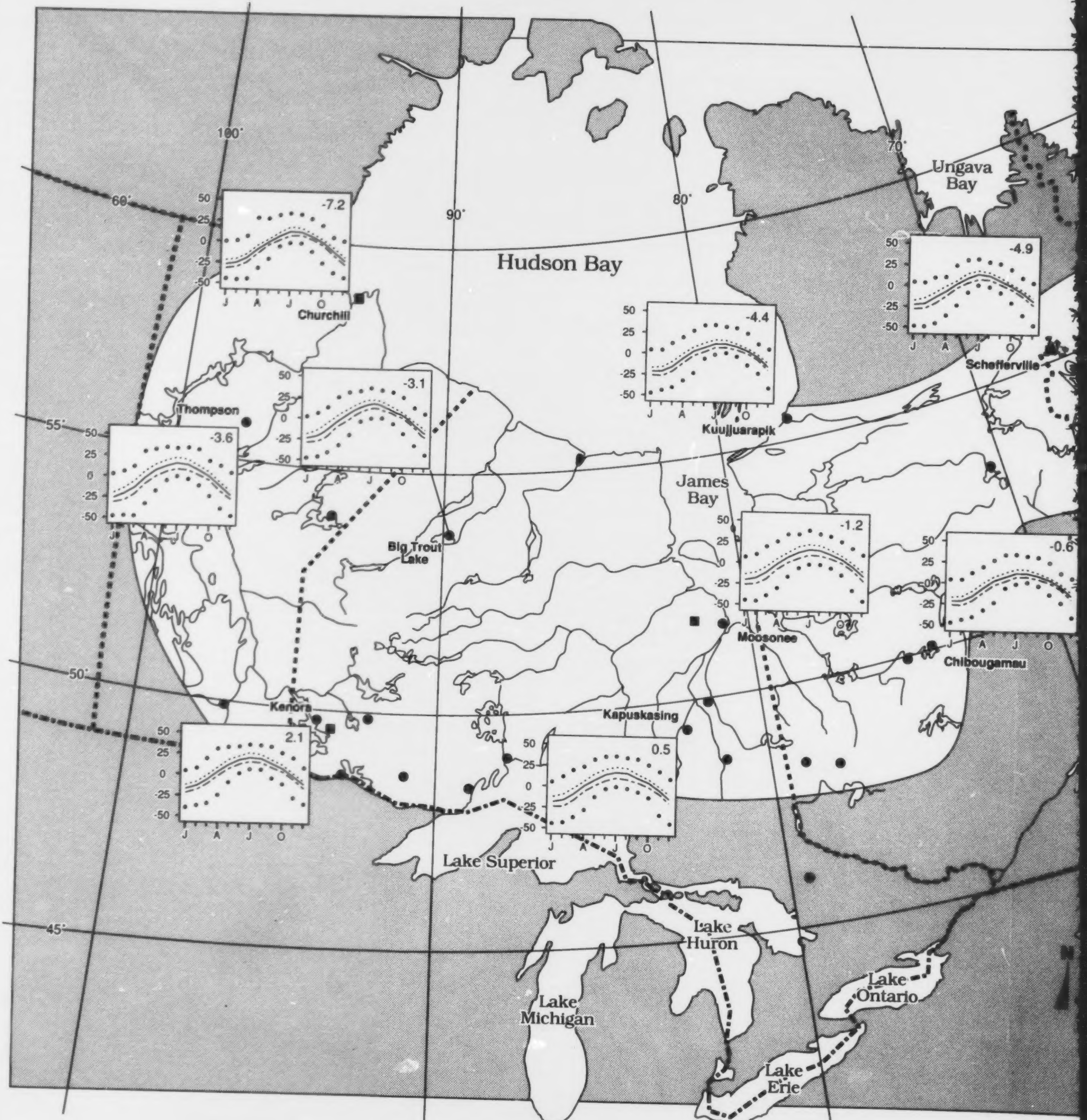
Mean daily temperature - July



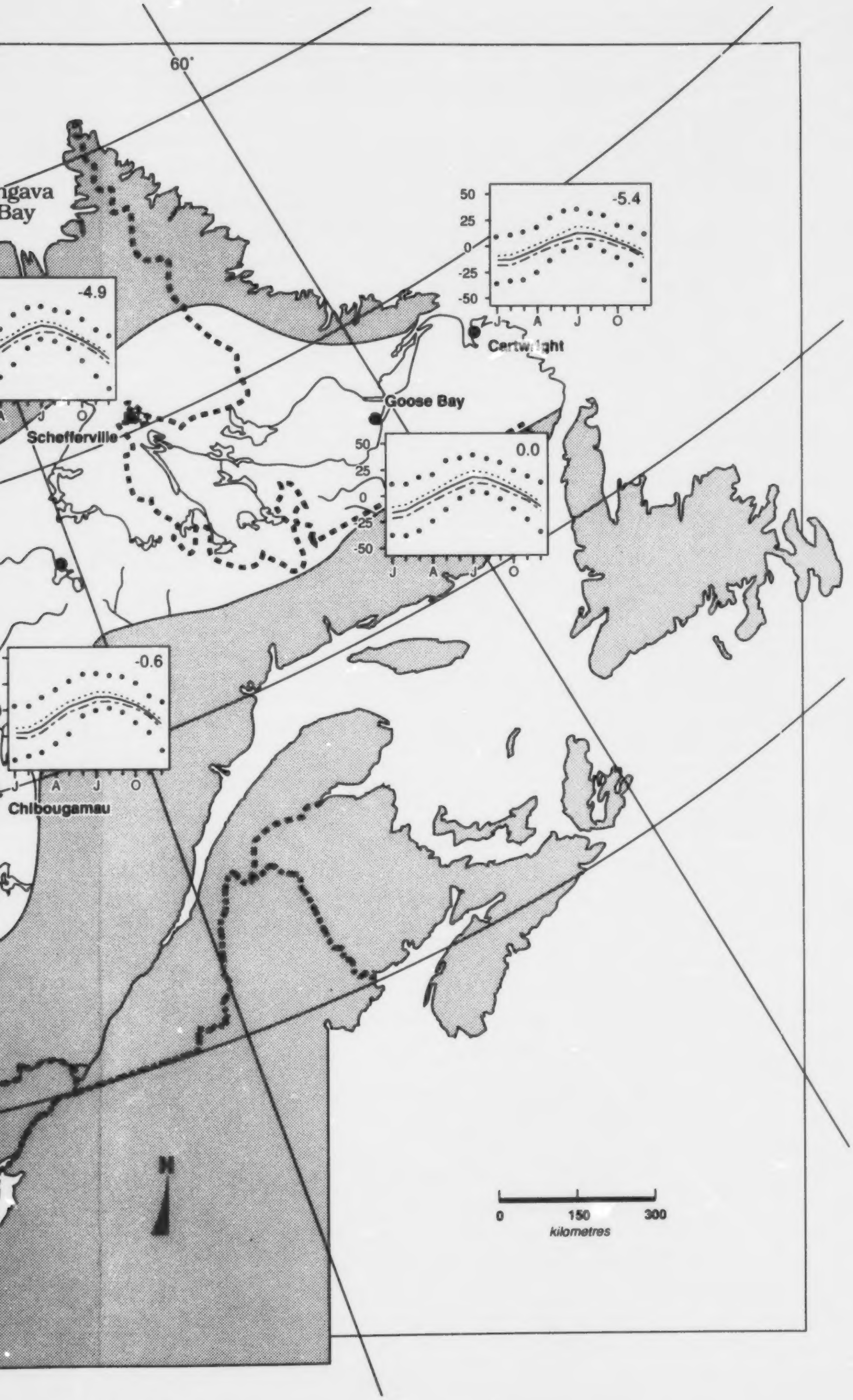
▬ mean daily temperature (°C) - July

Source:
Climatic Atlas Canada, 1:12.5 m
(Atmospheric Environment Service, 1984)

Projection: polar stereographic



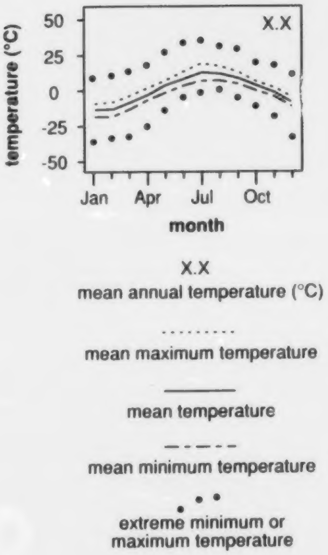
Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°
Churchill
Thompson
Big Trout Lake
Kenora
Kapuskasing
Moosonee
Kuujjuarapik
Schefferville
Chibougamau
-7.2
-3.1
-3.6
-4.4
-4.9
-1.2
-0.6
2.1
0.5
50
25
0
-25
-50
J
A
J
O



map 2.3.2C

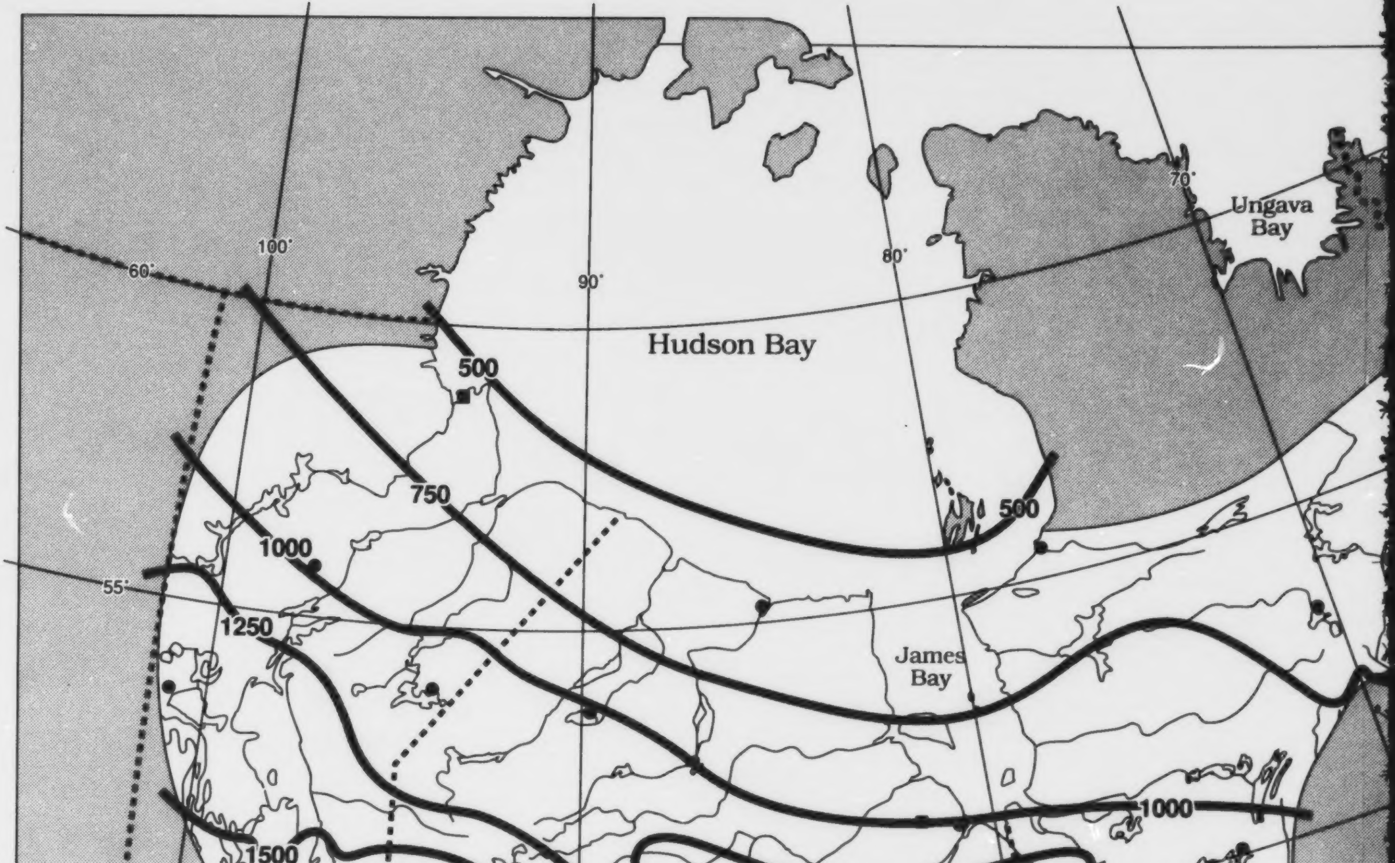
NORTHERN WETLANDS STUDY AREA

Mean monthly air temperature statistics for selected climate stations



Source:
Canadian Climate Centre,
National Archive

Projection: polar stereographic

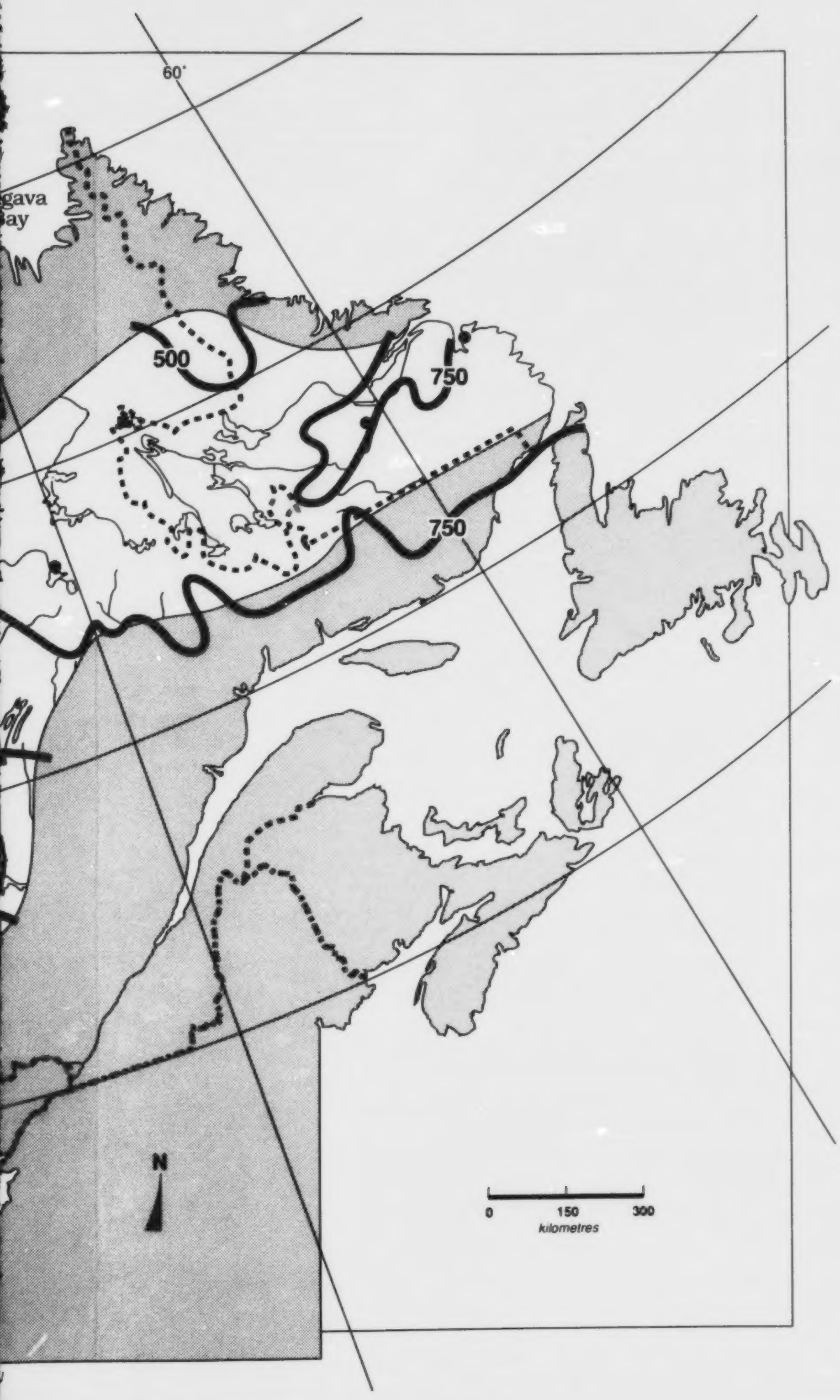


Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°
500
750
1000
1250
1500
1750
500
1000
1250
1250
1500

map 2.3.3

NORTHERN WETLANDS STUDY AREA

Annual total growing degree-days above 5°C



▬ annual total growing degree-days above 5°C

Source:
Climatic Atlas Canad [illegible]
(Atmospheric Environment Service, 1984)

Projection: polar stereographic

TABLE 2.3.2.

Growing season climate information for the period 1951 to 1980.

STATION	MEAN ANNUAL TOTAL GROWING DEGREE-DAYS ABOVE 5°C	MEAN ANNUAL GROWING SEASON (Days)	GROWING SEASON STARTS	GROWING SEASON ENDS	MEAN ANNUAL FREEZE-FREE (Days)
Thompson Manitoba	995	119	May 10	Sept 5	124
Churchill A Manitoba	555	101	June 15	Sept 23	109
Big Trout Lake Ontario	1049	136	May 16	Sept 28	139
Kenora A Ontario	1672	165	Apr 26	Oct 7	175
Kapuskasing A Ontario	1339	134	May 5	Sept 15	150
Moosonee Ontario	1102	123	May 18	Sept 17	139
Kuujjuarapik Québec	548	118	June 6	Oct 1	120
Chibougamau Québec	1159	133	May 9	Sept 18	150
Schefferville Québec	605	108	June 3	Sept 18	113
Goose Bay Labrador	1022	135	May 21	Oct 2	151
Cartwright Labrador	727	130	June 1	Oct 8	143

2.3.4 WIND

Wind plays an important role in numerous atmospheric, hydrological, biological and climatological processes as well as in gas exchange. Heat and vapour exchange between the atmosphere and the surface is dependent upon turbulence. Growth of plants is affected by wind speed primarily through its influence on evaporation and soil moisture. Wind direction partially controls the development of precipitation belts and shadows while winds cause the movement and drifting of snow.

Wind rose diagrams for selected stations for the windiest (winter) and least windy (summer) season are presented in Maps 2.3.4A and 2.3.4B. The wind roses display the mean percentage frequency of 5 knot wind speed classes in eight compass directions as well as the percentage frequency of calm. Hourly wind speed and direction data are based on one-minute-mean averages just prior to the hour of observation. The data were analyzed for the period 1953 to 1980 although stations such as Kuujjuarapik, Chibougamau, and Thompson have a shorter observation period.

The wind roses can be used to obtain an impression of the local wind directions and speeds. The Northern Wetlands Study area lies in the zone of westerlies where migrating cyclones and anticyclones predominate (Bryson and Hare 1974). However, the seasonal wind roses exhibit a range of prevailing wind directions. The wind pattern reflects the seasonal dominance of Pacific, Atlantic and Arctic airstreams modified by the local influence of topography, vegetation, and the presence of water bodies.

Surface features are important in controlling winds. At coastal sites, a land-sea breeze may be set up. Higher wind speeds occur where the wind is funnelled into and along valleys. Winds also increase at sites where friction is reduced such as over water and over low-lying vegetation. Lower wind speeds occur due to increased frictional drag in hilly or heavily forested sites.

2.3.5 PRECIPITATION

Precipitation is a general term applied to all forms of moisture that falls to the earth's surface. It includes drizzle, rain, hail and snow. Precipitation is important to wetland occurrence and development since it is a major factor controlling the regional water balance. It also influences vegetation distribution and growth. Permafrost development and depth are affected by the amount of snow on the ground. Exposed, snowless sites in northern areas generally support permafrost. The depth of snow on the ground gives an indication of the quantity of precipitation stored within a drainage basin and its potential impact on hydrology during spring melt.

Mean annual total precipitation for the period 1951 to 1980 is presented in Map 2.3.5A. Total precipitation is defined as the sum of rainfall plus the measured water equivalent of snow.

In Map 2.3.5B, mean annual snowfall (cm) and the mean maximum depth of snow (cm) are presented. The length of observation for these two parameters is different. Mean annual snowfall is based on data from 1951 to 1980. The mean maximum depth of snow is based on 2 sources: 1961 to 1970 snow course data and depth measurements at meteorological stations from 1955 to 1972 (Fisheries and Environment Canada 1978). At climate stations, depth (cm) of new snowfall is measured using a snow ruler at several representative sites away from drifted and exposed areas. The snowfall water equivalent (mm) is normally estimated to be 10 percent of depth based on an approximate density of snow. Real values can vary significantly. Snowfall water equivalent is measured at stations equipped with Nipher shielded snow gauges.

In the southern portion of the maps, the isohyets are more reliable since the observing network is more dense than in northern areas. Precipitation, particularly snow, can be underestimated due to gauge undercatch caused by strong winds at exposed observing stations (Goodison 1978, 1981).

The distribution and characteristics of precipitation are determined by controls such as atmospheric circulation, topography, aspect and relief, the daily radiative cycle, surface characteristics and proximity to large water bodies. In autumn or winter when the air is colder than the water, waterbodies promote precipitation. Precipitation is inhibited in late spring and summer when the air is warmer than the water. As a result of these processes, a snowbelt exists on the east shore of Hudson Bay. Heavy snowfall also occurs on the north coast of Labrador when unstable airstreams come off the Labrador Sea.

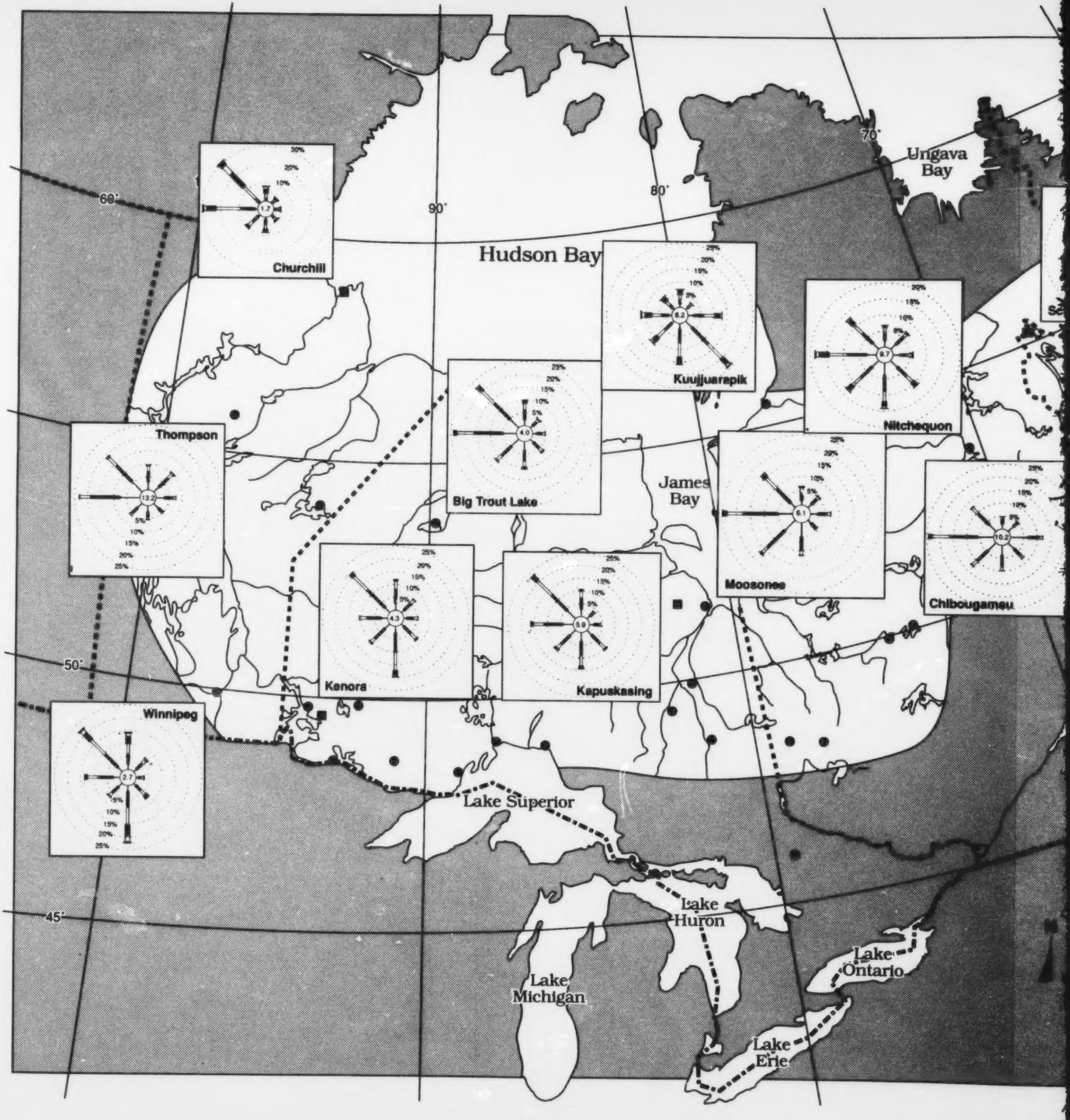
The Northern Wetland Study area has reliable, abundant and seasonally well-distributed precipitation. Northwest Manitoba is the driest area exhibiting a remnant of the Prairie influence. Total precipitation rises steadily southeastward from this point. It reaches its maximum in a band running along the north shore of the St. Lawrence River. Precipitable water is available from Pacific, Atlantic and Gulf of Mexico sources.

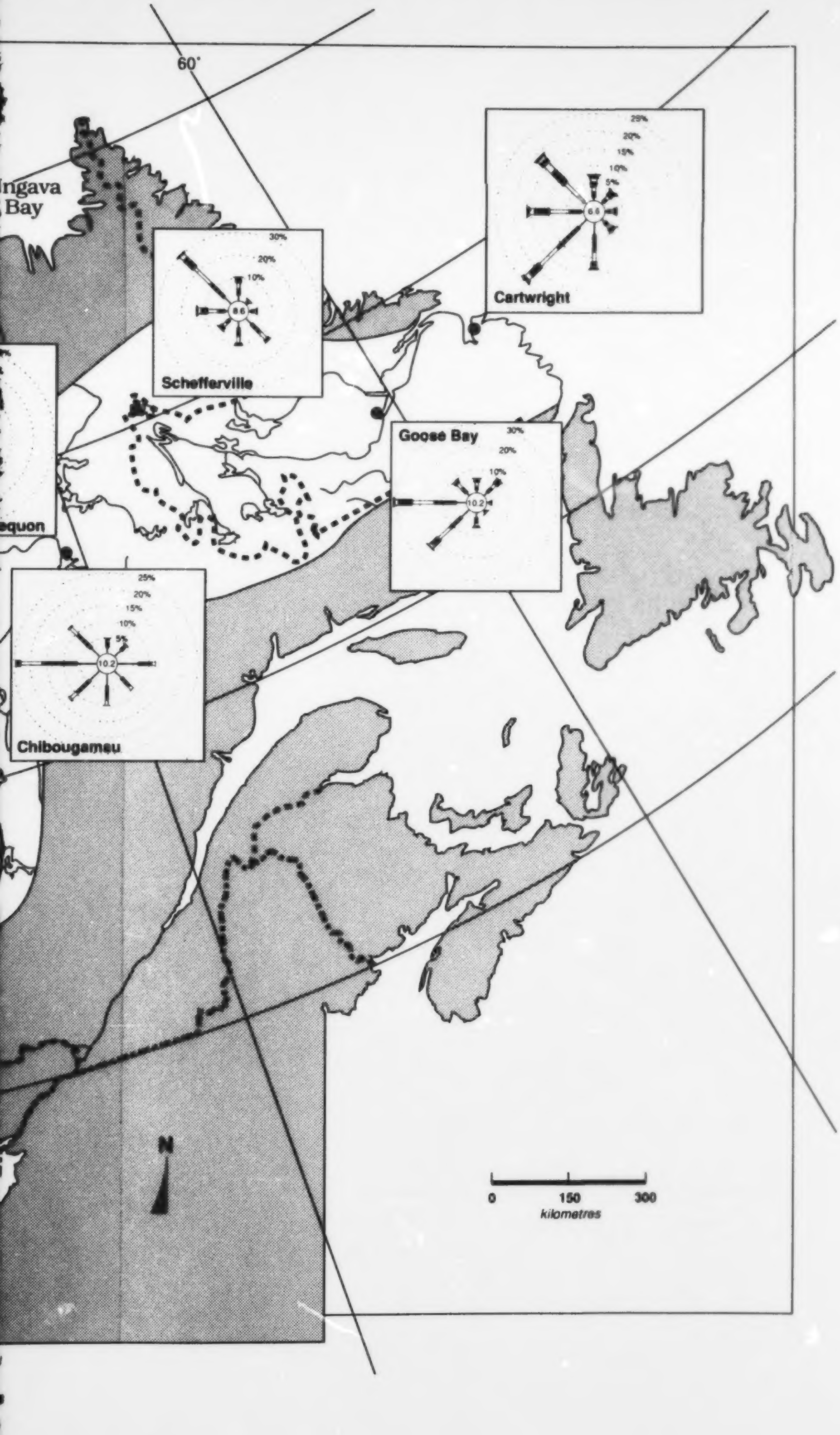
Snowfall in the eastern portion of the Northern Wetlands Study region is greater than the western portion (Map 2.3.5B). In the continental interior, insufficient atmospheric moisture is available for substantial snowfall (Hare and Hay 1970). Snowfall is higher to the lee of Lake Superior and in the Laurentian highlands. The variability from year to year in the amount of snowfall is a function of the frequency and origin of winter depressions and their trajectories (Wilson 1973).

In the Northern Wetlands Study area, the temperature remains below freezing for most of the winter retarding snowmelt and allowing snow accumulation throughout the winter. Vegetation type and abundance, windiness and topography contribute to the variable distribution of snow (McKay and Findlay 1971). Regions with deep accumulations usually correspond with areas that receive early, heavy snowfall and consistent freezing temperatures. The deeper snowcover in the east retards the warming effect of spring insolation and contributes to the Arctic and Boreal vegetation zones extending further south (Hare and Thomas 1979).

In general, 5 to 10 days after the fall of the mean daily temperature below 0°C snowcover becomes continuous. Snowmelt begins at or shortly before the date where the mean daily air temperature returns to 0°C. Melt can be completed in 2 to 4 weeks depending on the occurrence of fresh snowfall, cloudiness and prevailing weather (Hare and Hay 1970).

Graphs of total monthly precipitation (Map 2.3.5C) for 11 selected stations allows regional intercomparison of precipitation characteristics. The stations illustrate the increase in total precipitation from northwest to southeast. Churchill, Manitoba has a total average annual precipitation of 402 mm while Goose Bay, Labrador and Chibougamau, Québec in the east have a average total annual precipitation of 946 and 1000 mm, respectively. Snowfall constitutes from 48 percent (Schefferville, Québec) to 28 percent (Kenora, Ontario) of the total precipitation. All the stations except Goose Bay, Labrador demonstrate a summer maximum and a winter minimum in precipitation. There are roughly an equal number of days with precipitation in summer and in winter (AES, 1982a, b, c, d). However, the total amount of precipitation in summer is greater.

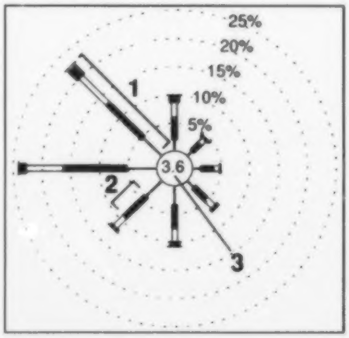

Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
60°
50°
45°
90°
80°
70°
Churchill
1.7
Thompson
13.2
Big Trout Lake
4.0
Kuujjuarapik
6.2
Nitchequon
9.7
Moosonee
6.1
Chibougamau
10.2
Kenora
4.3
Kapuskasing
5.9
Winnipeg
2.7
5%
10%
15%
20%
25%
30%



map 2.3.4A

NORTHERN WETLANDS STUDY AREA

Frequency of wind speed (knots) by direction - winter



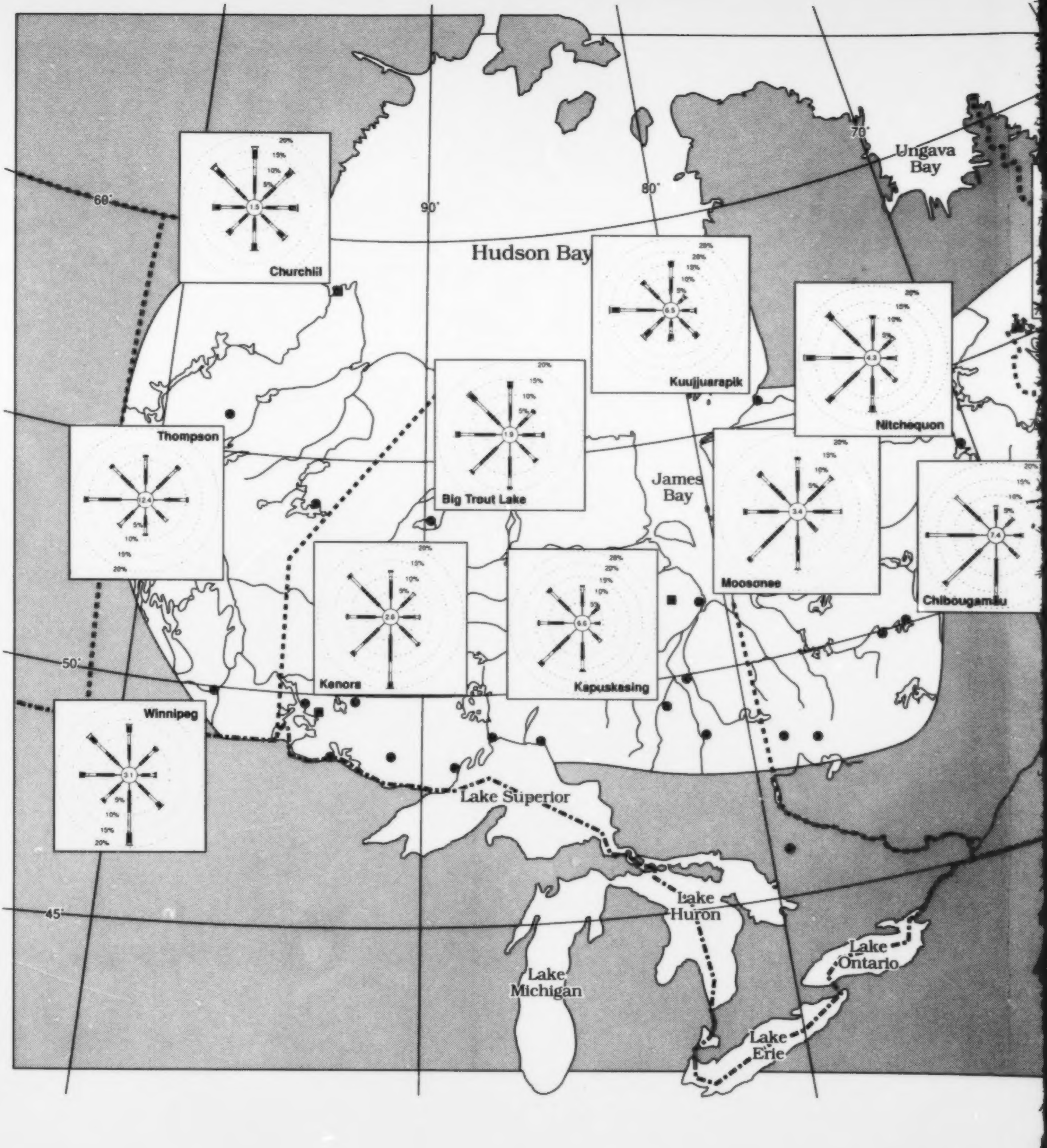
1 directional frequency of all wind speed classes (ie. 23% of winds are from the Northwest)

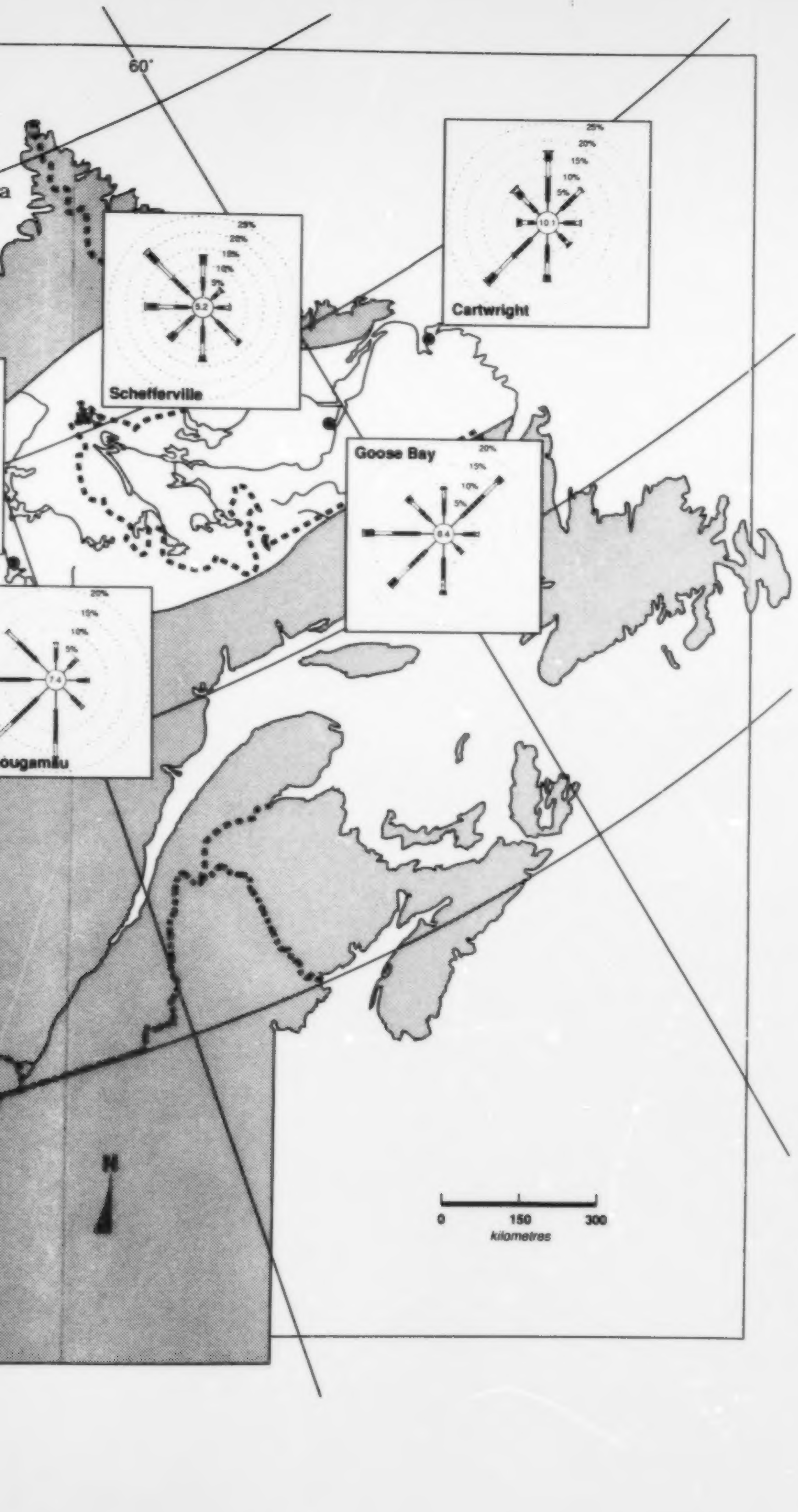
2 percent frequency of a 5 knot class (ie 5%of winds from the Southwest are 5-10 knots)

3 percent frequency of calm

Source:
Canadian Climate Centre,
National Archive

Projection: polar stereographic

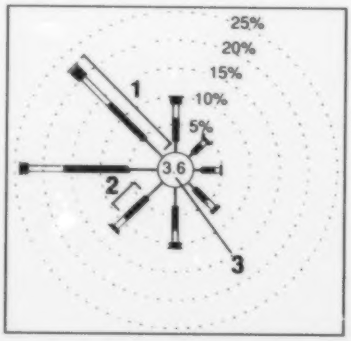

Hudson Bay
James Bay
Ungava Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
60°
50°
45°
90°
80°
70°
Churchill
1.5
Kuujjuarapik
6.5
Nitchequon
4.3
Thompson
12.4
Big Trout Lake
1.9
Moosonee
3.4
Chibougamau
7.4
Kenora
2.6
Kapuskasing
5.6
Winnipeg
3.1
5%
10%
15%
20%



map 2.3.4B

NORTHERN WETLANDS STUDY AREA

Frequency of wind speed (knots) by direction - summer



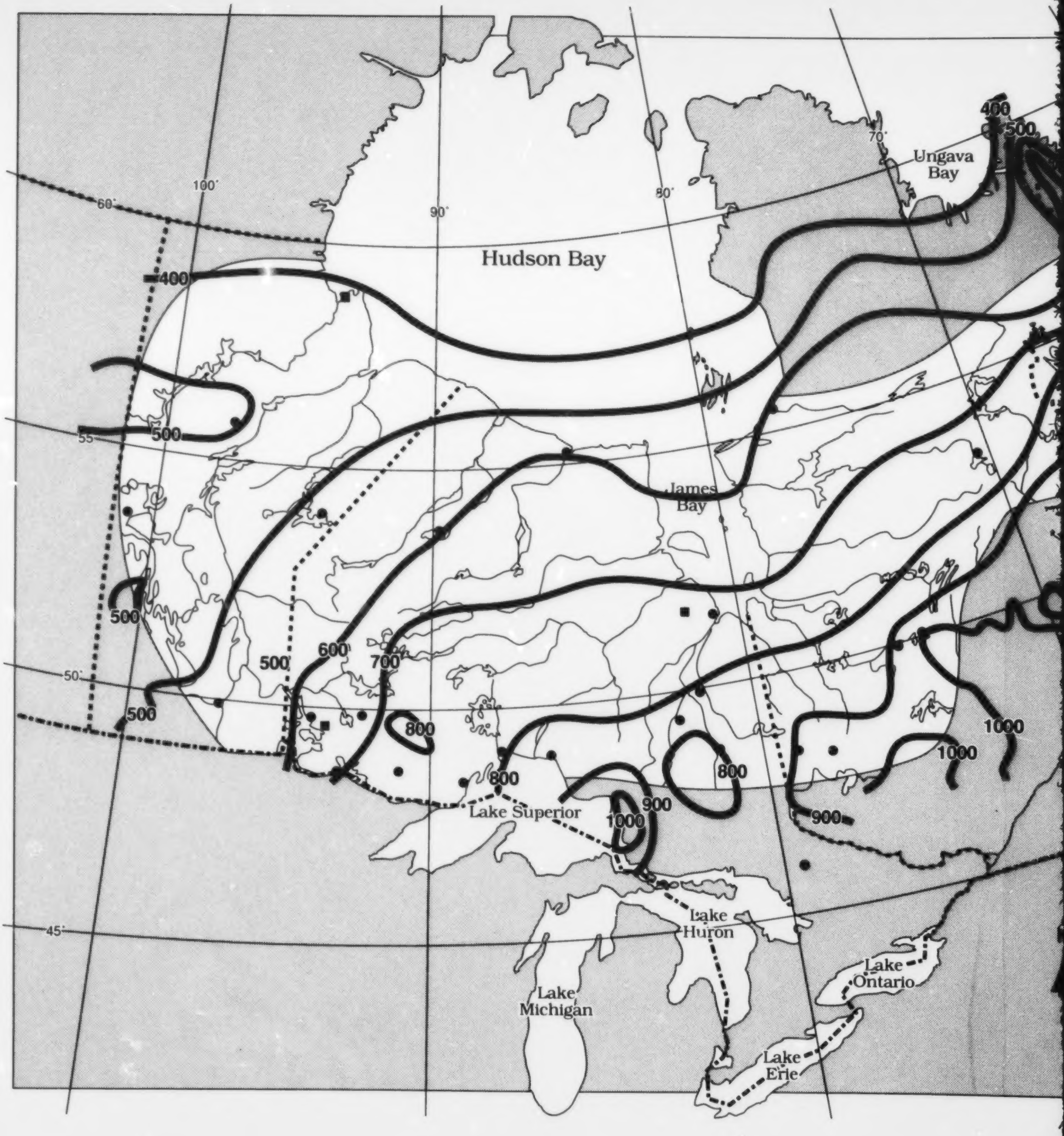
1 directional frequency of all wind speed classes (ie. 23% of winds are from the Northwest)

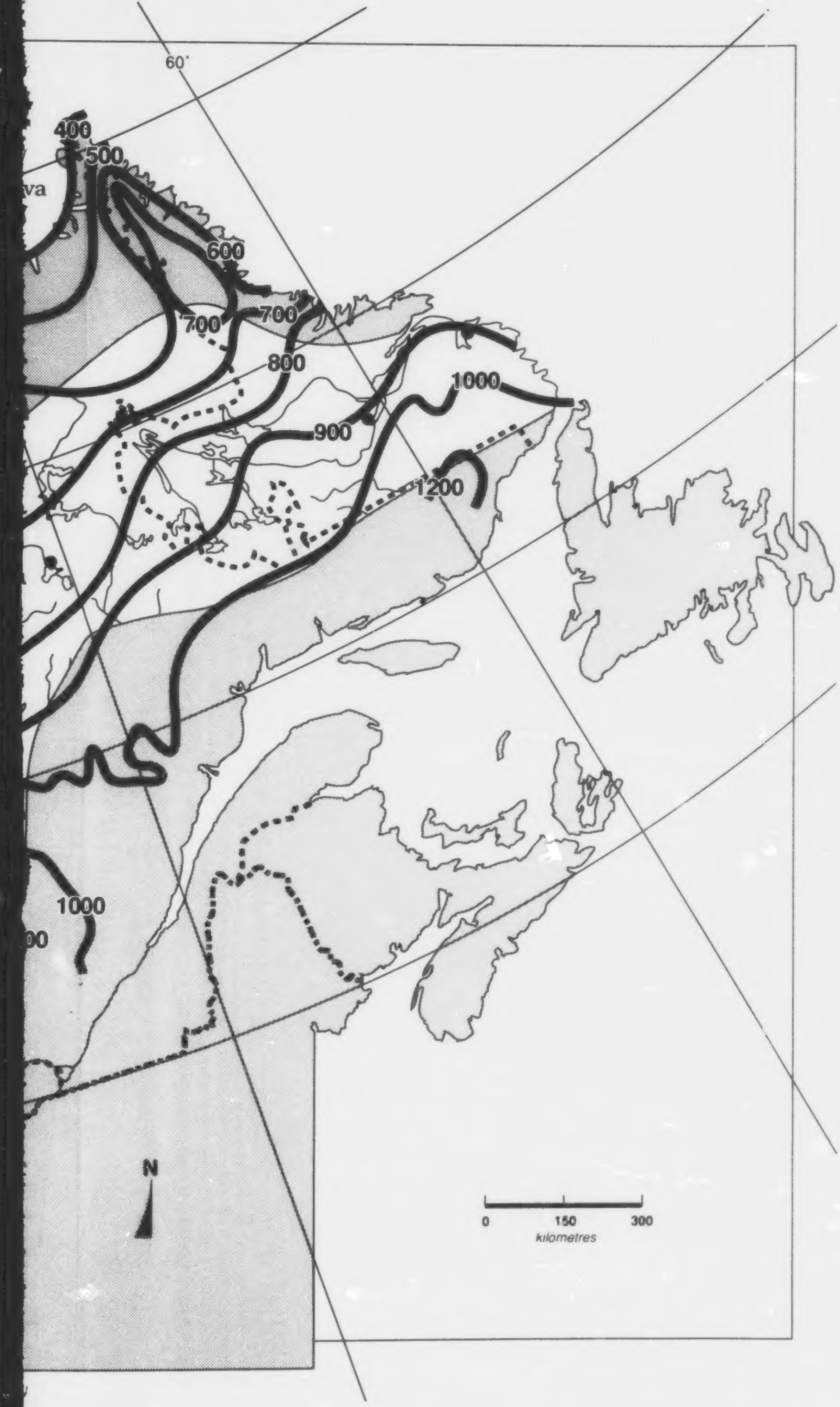
2 percent frequency of a 5 knot class (ie 5%of winds from the Southwest are 5-10 knots)

3 percent frequency of calm

Source:
Canadian Climate Centre,
National Archive

Projection: polar stereographic


400
500
70°
Ungava Bay
100°
60°
90°
80°
Hudson Bay
400
500
55
James Bay
500
500
600
700
50°
500
800
1000
1000
800
800
900
1000
900
Lake Superior
45°
Lake Huron
Lake Ontario
Lake Michigan
Lake Erie



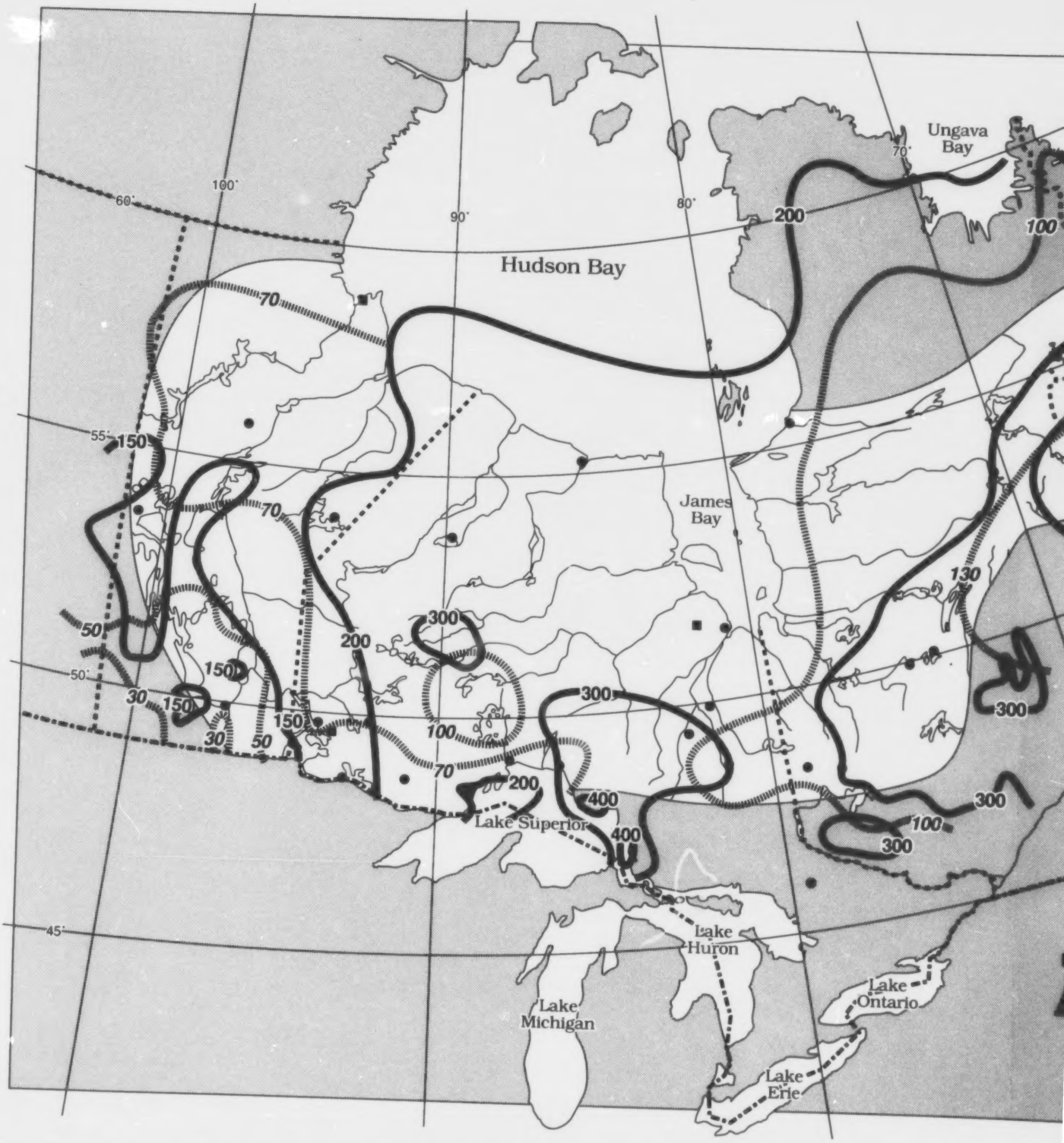
map 2.3.5A
NORTHERN WETLANDS STUDY AREA

Mean Annual Total Precipitation

▬ mean annual total precipitation (mm)

Source
Climatic Atlas Canada, 1:12.5 m.
(Atmospheric Environment Service, 1986)

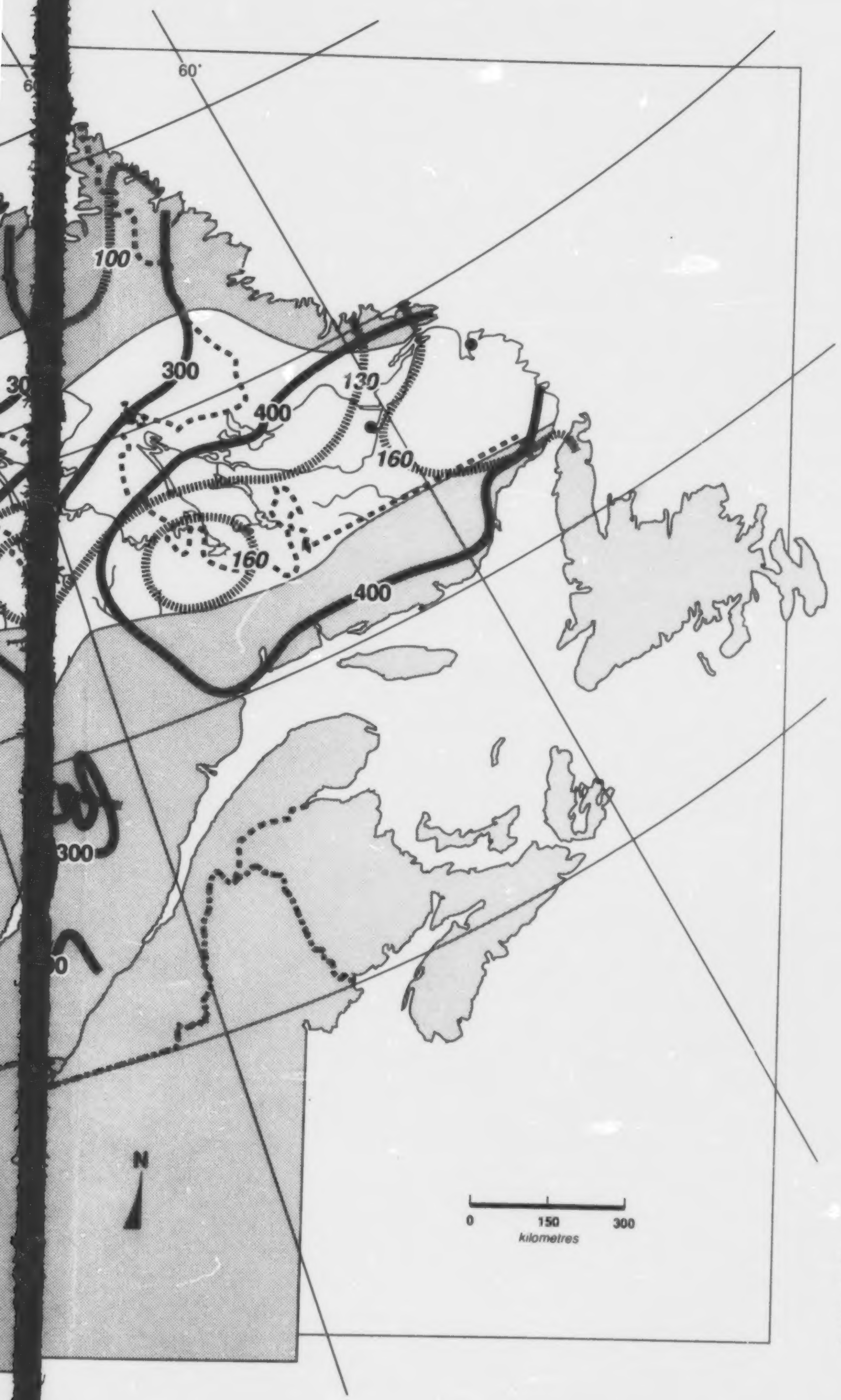
Projection: polar stereographic


Ungava Bay
70°
100°
60°
90°
80°
200
100
Hudson Bay
70
55°
150
70
James Bay
130
300
200
50
150
50°
30
150
150
300
100
30
50
70
300
200
400
Lake Superior
400
300
100
300
45°
Lake Huron
Lake Ontario
Lake Michigan
Lake Erie

map 2.3.5B

NORTHERN WETLANDS STUDY AREA

Mean annual snowfall and mean maximum depth of snow



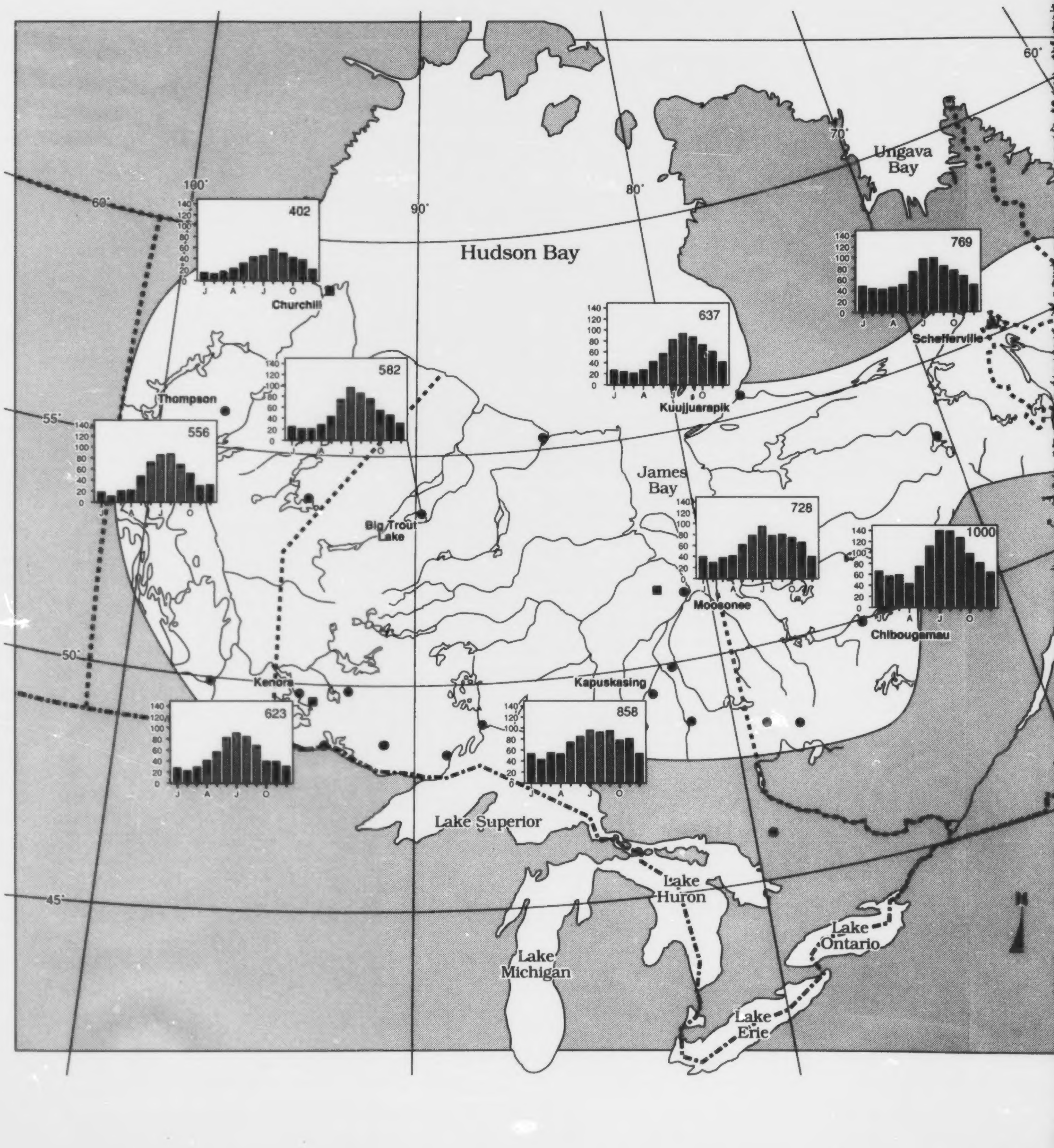
▬ mean annual total snowfall (cm)

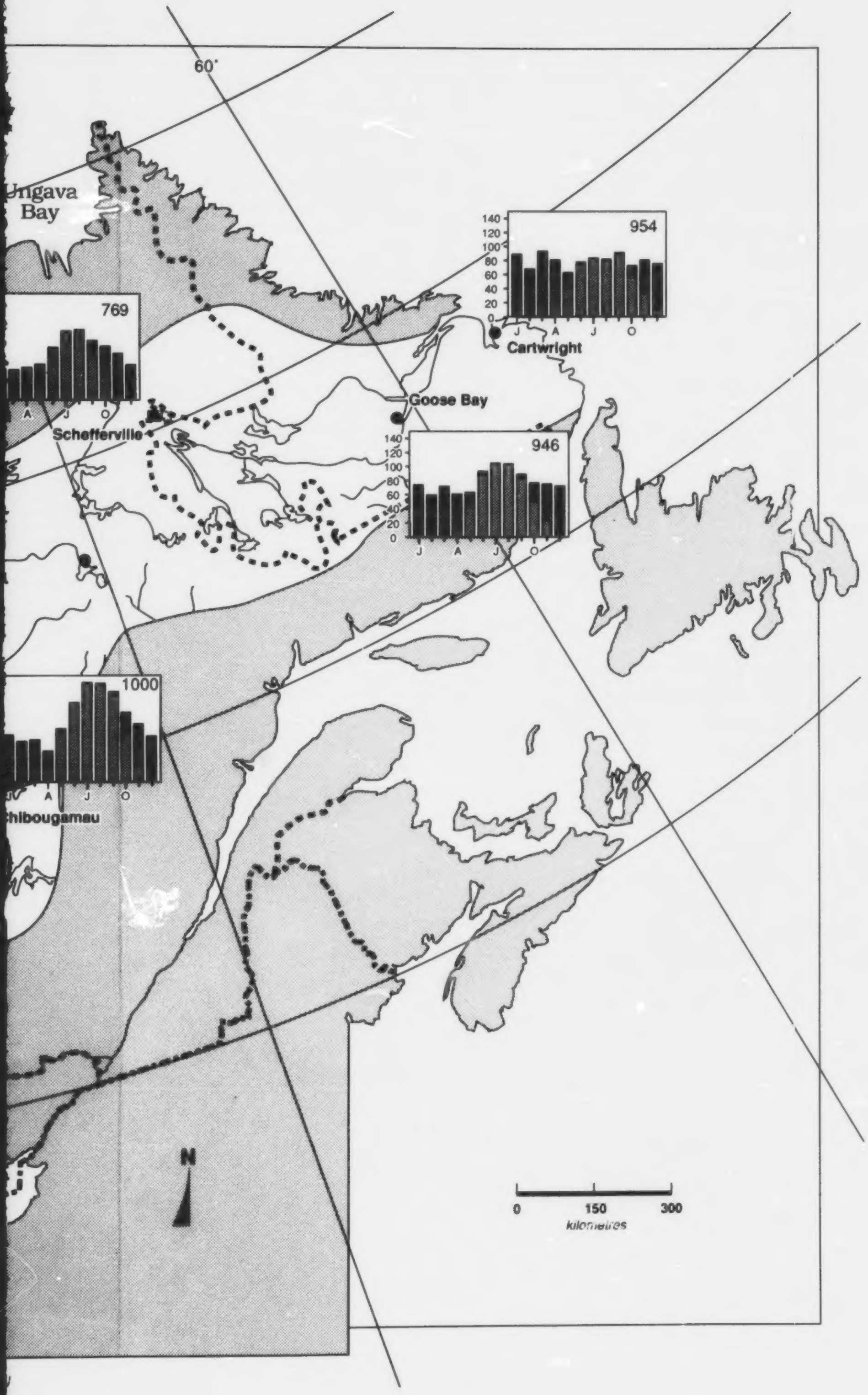
▮▮▮ mean maximum depth of snow (cm)

Source
Hydrological Atlas of Canada, 1:10 m.
(Fisheries and Environment Canada, 1978)

Climatic Atlas Canada, 1:12.5 m.
(Atmospheric Environment Service, 1986)

Projection: polar stereographic

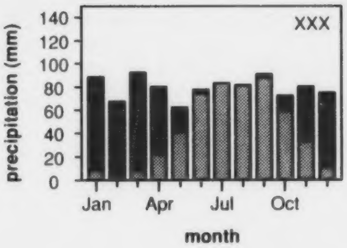

Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
60˚
70˚
80˚
90˚
100˚
55˚
50˚
45˚
N
Churchill
Thompson
Big Trout Lake
Kenora
Kapuskasing
Moosonee
Kuujjuarapik
Schefferville
Chibougamau
402
582
556
637
769
728
1000
623
858
140
120
100
80
60
40
20
0
J
A
J
O



map 2.3.5C

NORTHERN WETLANDS STUDY AREA

Mean monthly total precipitation at selected climate stations



XXX total precipitation (mm)

▮ snowfall water equivalent (mm)

▨ rainfall (mm)

Source:
Atmospheric Environment Service, 1982 a,b,c,d

Projection: polar stereographic

2.3.6 REFERENCES

Atmospheric Environment Service. 1982a. Canadian Climate Normals 1951-80, Temperature and Precipitation—Québec. Supply and Services Canada, Ottawa: 216p.

Atmospheric Environment Service. 1982b. Canadian Climate Normals 1951-80, Temperature and Precipitation—Atlantic Provinces. Supply and Services Canada, Ottawa: 136p.

Atmospheric Environment Service. 1982c. Canadian Climate Normals 1951-80, Temperature and Precipitation—Prairie Provinces. Supply and Services Canada, Ottawa: 429p.

Atmospheric Environment Service. 1982d. Canadian Climate Normals 1951-80, Temperature and Precipitation—Ontario. Supply and Services Canada, Ottawa: 254p.

Atmospheric Environment Service. 1982e. Canadian Climate Normals 1951-80, Volume 4—Degree-Days. Supply and Services Canada, Ottawa: 280p.

Atmospheric Environment Service. 1982f. Canadian Climate Normals 1951-80, Volume 5—Wind. Supply and Services Canada, Ottawa: 283p.

Atmospheric Environment Service. 1984. *Climatic Atlas Climatique—Canada*. Map Series 1—Temperature and Degree-Days. Supply and Services Canada, Ottawa.

Atmospheric Environment Service. 1986. *Climatic Atlas Climatique—Canada*. Map Series 2—Precipitation. Supply and Services Canada, Ottawa.

Bryson, R.A. and F.K. Hare. 1974. The climates of North America. *In. Climates of North America, World Survey of Climatology Volume 11*, R.A. Bryson and F.K. Hare (editors), Elsevier Scientific Publishing Co., N.Y.: 1-48.

Chang, Jen-Hu. 1970. Potential photosynthesis and crop productivity. *Annals of the Assoc. American Geog.*, 60: 92-101.

Chapman, L.J. and M.D. Thomas. 1968. The Climate of Northern Ontario. Meteorological Branch, Dept. of Transport, Climatological Studies No. 6: 58p.

Danielson, E.W. 1969. The surface heat budget of Hudson Bay. McGill University, Marine Sciences Manuscript Rep. No. 9: 196p.

Fisheries and Environment Canada. 1978. *Hydrological Atlas of Canada*. Supply and Services Canada, Ottawa.

Goodison, B.E. 1978. Accuracy of Canadian snow gauge measurements. *J. Applied Meteorology*, 17(10): 1542-1548.

Goodison, B.E. 1981. Compatibility of Canadian snowfall and snow cover data. *Water Resources Res.*, 17(4): 893-900.

Hare, F.K. 1950. Climate of the Eastern Canadian Arctic and Sub-arctic, with Special Reference to Northern Québec, Labrador, Newfoundland and the Surrounding Seas. PhD dissertation, McGill University: 315p.

Hare, F.K. and J.E. Hay. 1974. The climate of Canada and Alaska. *In. Climates of North America, World Survey of Climatology Volume 11*, R.A. Bryson and F.K. Hare (editors), Elsevier Scientific Publishing Co., N.Y.: 49-192.

Hare, F.K. and R. W. Longley. 1953. The Climate of Québec and Labrador. Meteorol. Branch, Dept. of Transport, Toronto: 134p.

Hare, F.K. and J.C. Ritchie. 1972. The boreal bioclimates. *The Geographical Review*, 62(3): 333-365.

Hare, F.K. and M.K. Thomas. 1979. *Climate Canada*. 2nd Ed. Wiley Publications of Canada Ltd., Toronto: 230p.

Hay, J.E. 1970. Aspects of the Heat and Moisture Balance of Canada. PhD dissertation, University of London: 307p.

Hay, J.E. 1977. An Analysis of Solar Radiation Data for Selected Locations in Canada. Dept. Supply and Services. Hull, P.Q. Atmospheric Environment Service, Fisheries and Environment Canada, Climatological Studies No. 32: 158p.

Hutton, C.L.A. and W.A. Black. 1975. Ontario Arctic Watershed. Lands Directorate, Environment Canada, Map Folio No. 2: 107p.

Kendrew, W.G. and B.W. Currie. 1955. The Climate of Central Canada—Manitoba, Saskatchewan, Alberta and the Districts of Mackenzie and Keewatin. Queen's Printer, Ottawa: 194p.

Longley, R.W. 1972. The Climate of the Prairies Provinces. Atmospheric Environment, Environment Canada, Toronto. Climatological Studies No. 13: 79p.

McKay, G.A. and Findlay, B.F. 1971. Variation of snow resources with climate and vegetation in Canada. Proc. 39th Western Snow Conference, Billings, Montana, April 20-22, 1971: 17-26.

Monteith, J.L. 1965. Light distribution and photosynthesis in field crops. *Annals of Botany, new series*, 29:17-37.

Potter, J.G. 1965. Snow Cover. Meteorological Branch, Dept. of Transport, Climatological Studies No. 3: 69p.

Robertson, G.W. 1966. The light composition of solar and sky spectra available to plants. *Ecology*, 47(4): 640-643.

Thomas, M.K. 1953. Climatological Atlas of Canada. Division of Building Research, National Research Council, and Meteorological Division, Dept. of Transport. Nat. Res. Council, No. 3151, Ottawa: 253p.

Thompson, H.A. 1968. The climate of Hudson Bay. *In. Science, History and Hudson Bay, Vol. 1*, C.S. Beals (editor), Dept. Energy, Mines and Resources, Queen's Printer, Ottawa: 263-286.

Titus, R.L. and E.J. Truhlar. 1969. A New Estimate of Average Global Solar Radiation in Canada. Meteorological Branch, Dept. of Transport, CLI 7-69: 26p.

Wilson, C.V. 1973. The Climate of Québec. Part Two: The Application of Climatic Information. Atmospheric Environment, Environment Canada, Climatological Studies No. 11: 110p.

Wilson, C.V. 1975. The Climate of Québec Energy Considerations. Atmospheric Environment, Environment Canada, Climatological Studies No. 23: 120p.

2.4 AIR CHEMISTRY

As a result of biological activity of micro-organisms, wetlands are sources and sinks of atmospheric gases. The chemical environment in which terrestrial biota function can influence gas exchange between the surface and atmosphere. For instance, the input of nitrogen and phosphate to northern wetlands—which are generally deficient in these nutrients—may stimulate biological production and thereby enhance the exchange of gases.

2.4.1 EMISSIONS AND DEPOSITION OF SO_2, NO_x AND REACTION PRODUCTS

Emissions of sulphur dioxide (SO_2) and oxides of nitrogen (NO_x), along with their atmospheric chemical transformation products (acidic salts of sulphate and nitrate), are transported by wind and deposited to the earth's surface either by direct interaction (dry deposition) or by rain and snowfall (wet deposition).

The Canadian wetland regions are not totally beyond the influence of human activities. Via the atmosphere, North American emissions of oxides of sulphur and nitrogen (Map 2.4.1) can substantially augment natural inputs in the southern and eastern parts of the eastern North American wetlands. Map 2.4.2 shows the pattern of annual inputs of acidity, nitrates, ammonium and sulphates in the wetlands regions by rain and snowfall (assembled from the National Atmospheric Chemistry Data Base).

Emission measurements and estimates are the responsibility of the State and Provincial pollution control agencies. This information is aggregated by the Federal Environmental Protection agencies to produce country-wide estimates. For the purpose of regional scale air pollution modelling, emissions are required on a gridded basis. Since 1980 was chosen as the base year for many modelling activities, much effort was put into generating the gridded values for annual SO_2 and NO_x emissions shown in Map 2.4.1. This map serves to illustrate that, on a regional scale, pollution sources are concentrated in the eastern half of North America.

For SO_2, the highest emissions are from power plants and metal smelters. For NO_x, the highest emissions are from automobile exhaust and power plants.

2.4.2 THE ATMOSPHERIC REGION OF INFLUENCE FOR THE HUDSON BAY LOWLAND

The movement of air links emissions with deposition. The concept of an 'atmospheric region of influence' was introduced by Summers and Young (1987) as an appropriate atmospheric analog to the watershed. Hydrological watersheds are fixed in space by topographical features. All locations within a given watershed have the same defined watershed boundary. In contrast, air is generally free to move without the same physical constraints. Thus, the atmospheric region of influence (AROI) is unique to each location and can only be expressed in statistical probability terms. A full description of how the AROI is calculated for the Great Lakes region is given by Summers and Young (1987). A brief description of the technique follows, and the results for Churchill, Kenora, Experimental Lakes Area (ELA), Fraserdale and Schefferville are presented.

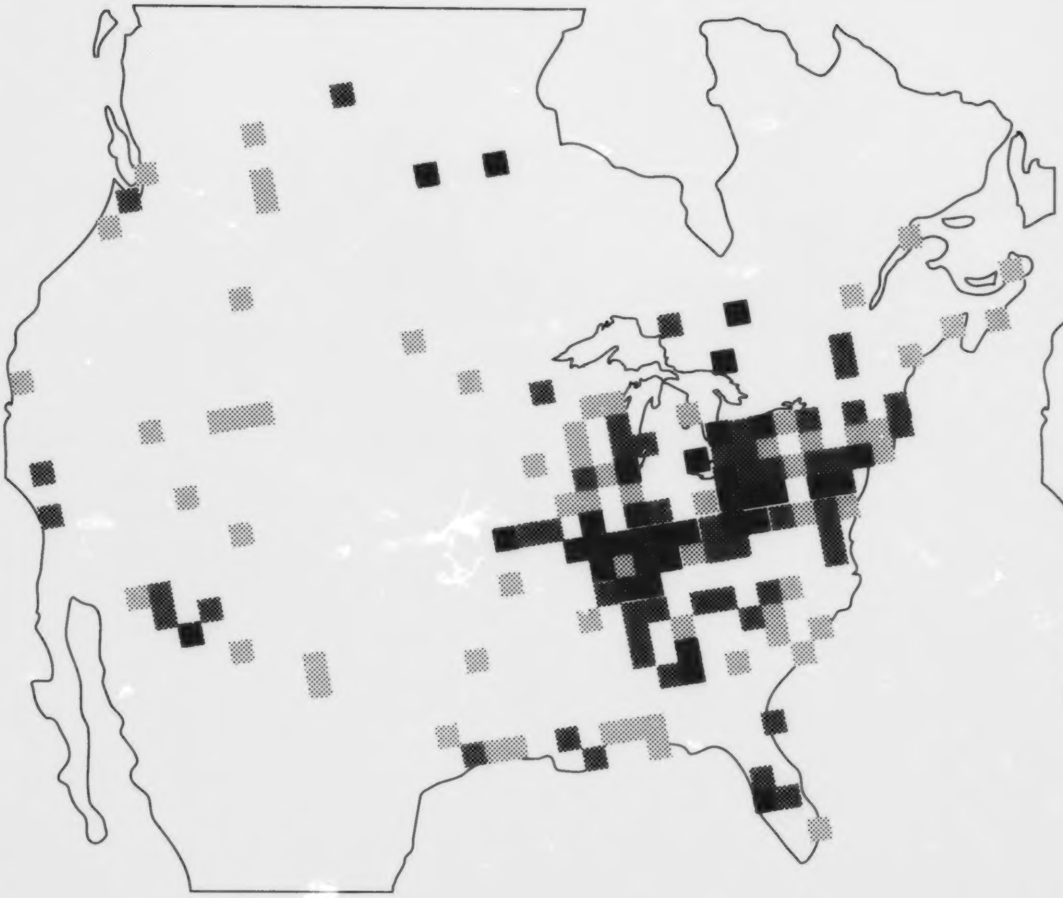
2.4.2.1 THE ONE-DAY REGION OF INFLUENCE

Air parcel trajectories at a height of 925 mb (approximately 800 m above sea-level) are used. This is representative of the flow of the near-surface layer through which anthropogenic pollutants and natural emissions are mixed. For each of the eight major wind sectors, the end points of the trajectories going back in time for 24 hours from the selected site are plotted. The distances containing 25 percent, 50 percent (the median value), 75 percent and 100 percent of the end points are shown in Map 2.4.3. Consider, for instance, the results for Fraserdale. The 100 percent line shows that, at Fraserdale, the extreme maximum distance travelled is 1760 km from the north. The maximum (100 percent line) encloses all cases analyzed over the 9-year period from 1979 to 1987 and this defines the outer limit for the "one-day region of influence". For pollutants that can persist in the atmosphere for only one day, this line represents the closest atmospheric analogy to a watershed. Whereas the 100 percent line represents distance of travel in the most extreme cases, the 50 percent line marks the most probable distance travelled by an air parcel.

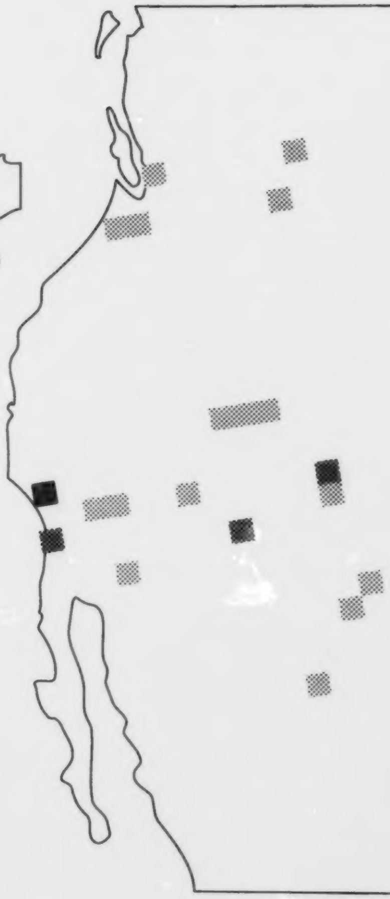
The results for the one-day AROI at the other 3 sites are also shown in Map 2.4.3. Both the general shape and distances shown by the isopleths are quite similar from site to site; this is a manifestation of the fact that all sites are located in the mid-latitude westerly belt and, therefore, all are subject to the same sequence of wind patterns, with the passage of alternating high and low pressure systems.

2.4.2.2 EXTENDED REGION OF INFLUENCE

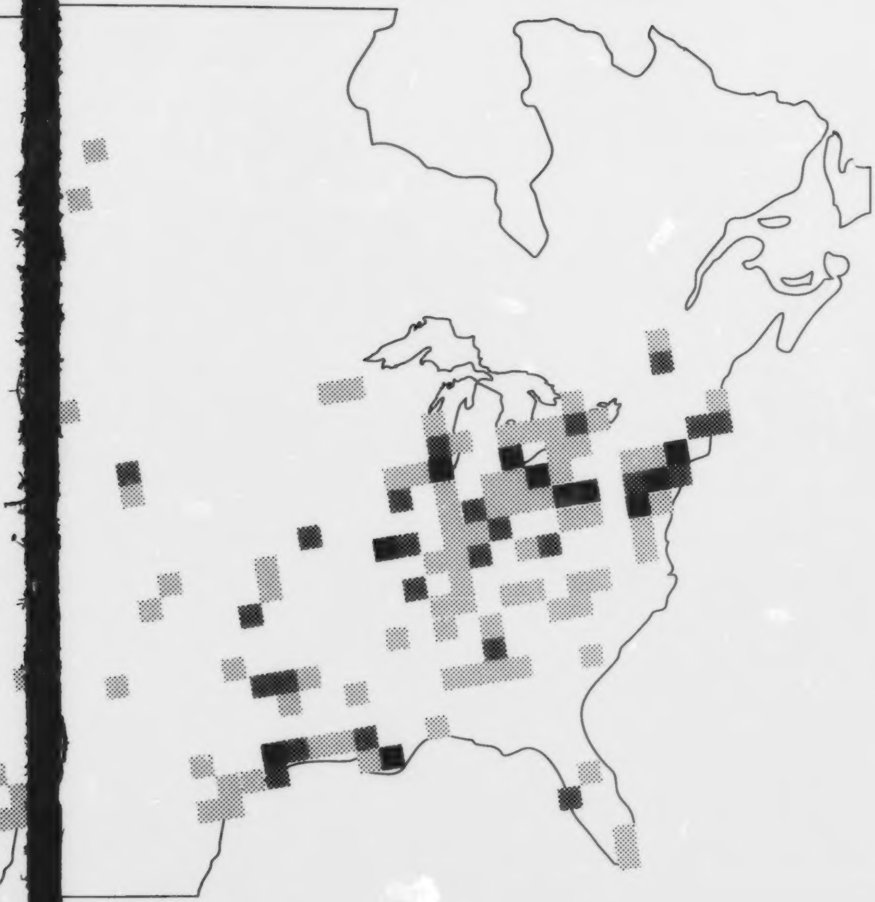
The same procedure described above can be used for any length of air parcel travel time, although the errors in trajectory calculations tend to increase rapidly beyond five days. In Map 2.4.4 the most probable travel distances for travel times of one to five days are shown for air arriving at Fraserdale for the whole 9 year period. Note that as the travel time increases, the shape of the AROI becomes less circular about the receptor point. At 5 days, the travel distance from the north and northwest is about double that from the southerly sectors.



SO$_2$ emissions in 1980



NO$_x$ emissions in 1980



ns in 1980

map 2.4.1

NORTHERN WETLANDS STUDY AREA

North American SO_2 and NO_X annual emissions-1980

Emissions
(kilotonne of SO_2 and NO_x as NO_2 per 127 km grid)

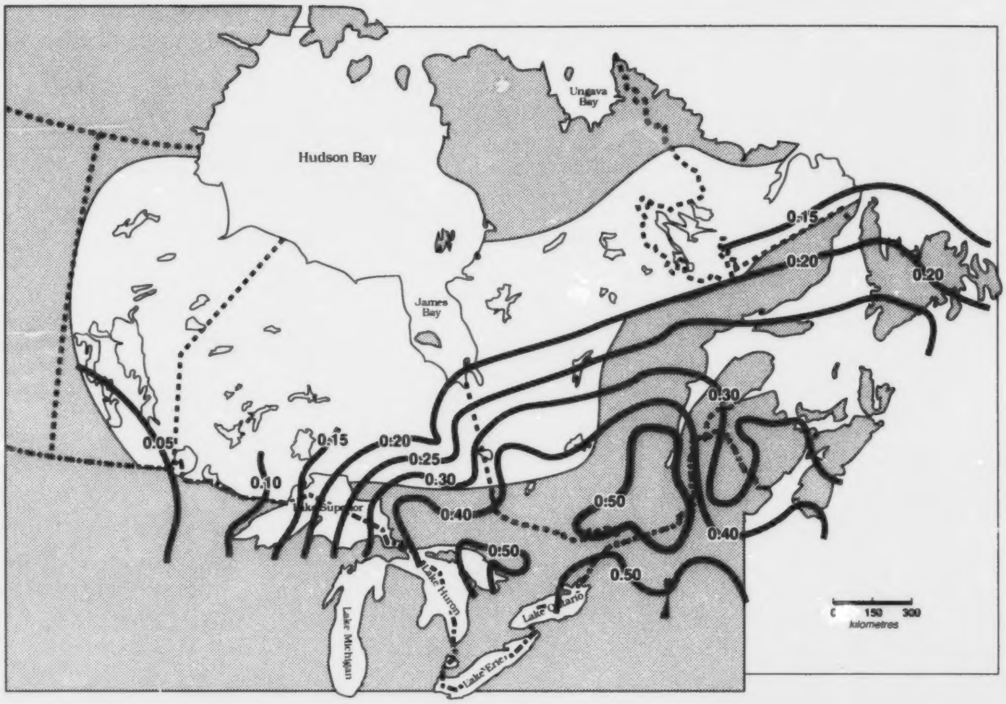
■ >400

■ 200 to 399

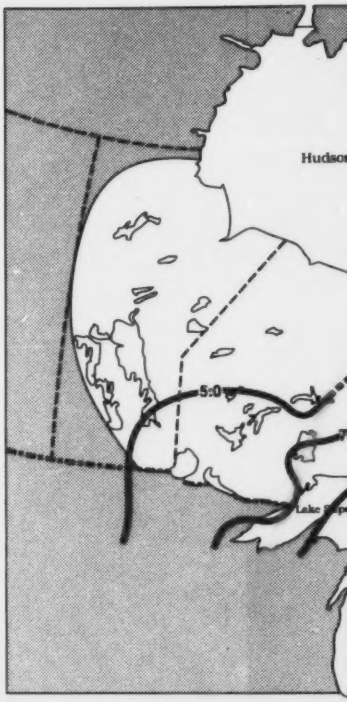
▩ 100 to 199

░ 50 to 99

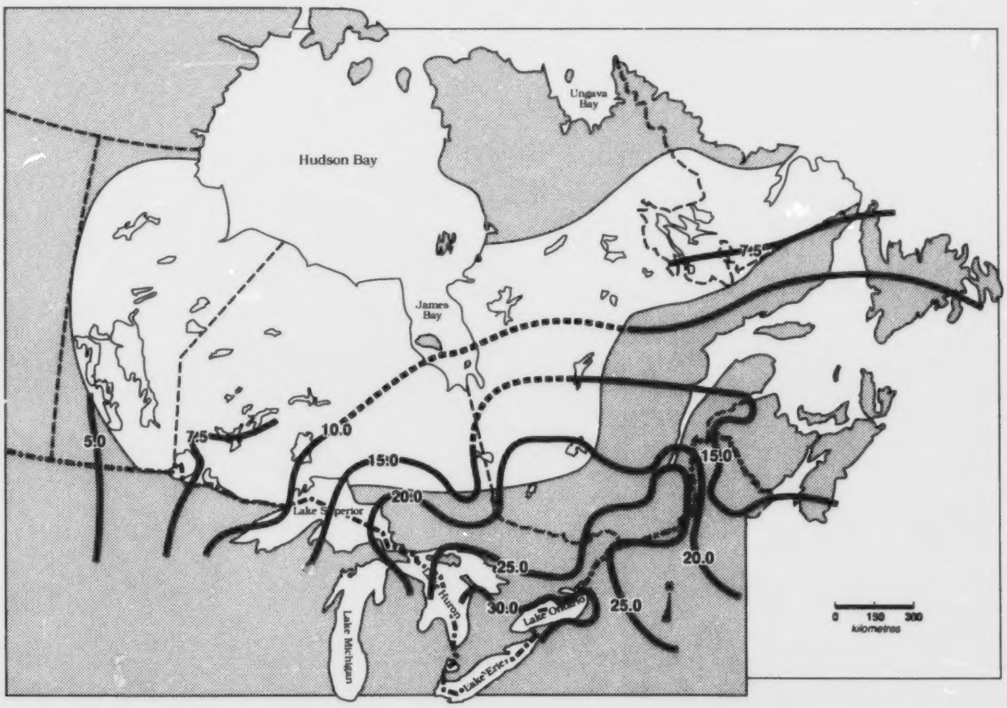
Source:
U.S. Environmental Protection Agency, 1989.



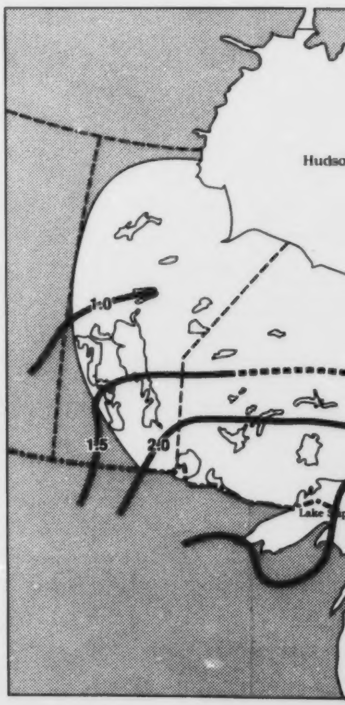
5-year (1982-1986) mean wet H^+ deposition



5-year (1982-1986) mean wet NO_3^-



5-year (1982-1986) mean wet non-sea salt SO_4^{2-} deposition

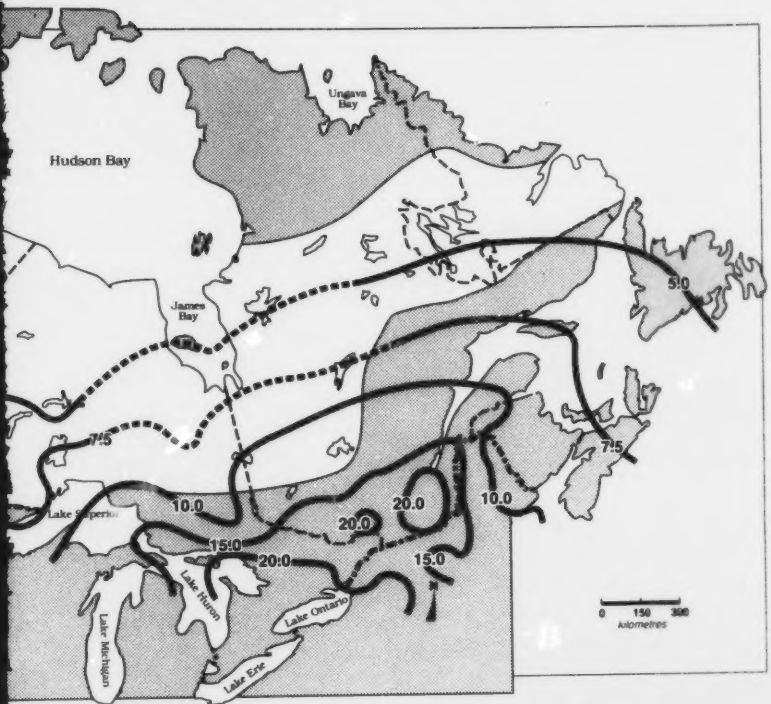


5-year (1982-1986) mean wet NH_4^+

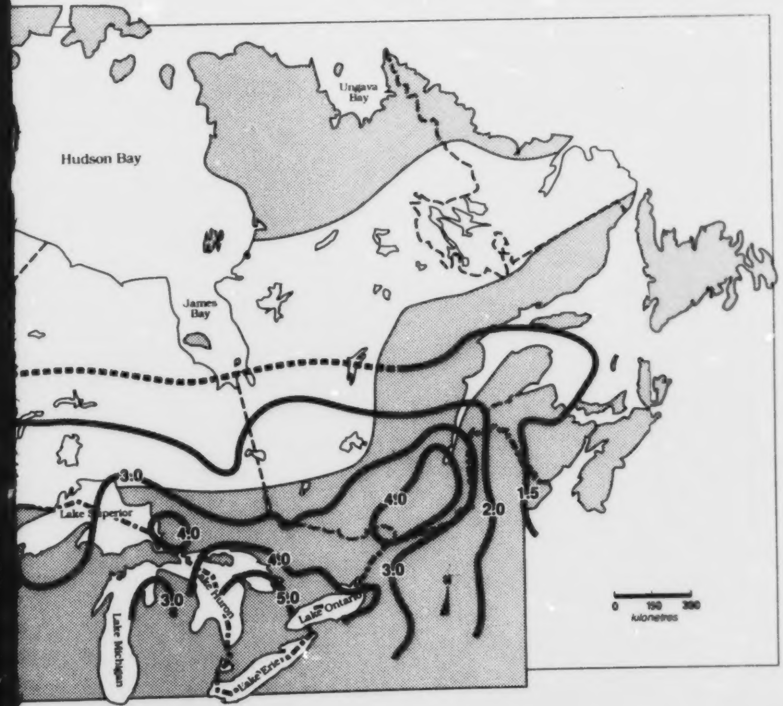
map 2.4.2

NORTHERN WETLANDS STUDY AREA

Wet deposition of acids to wetlands



wet NO_3^- deposition

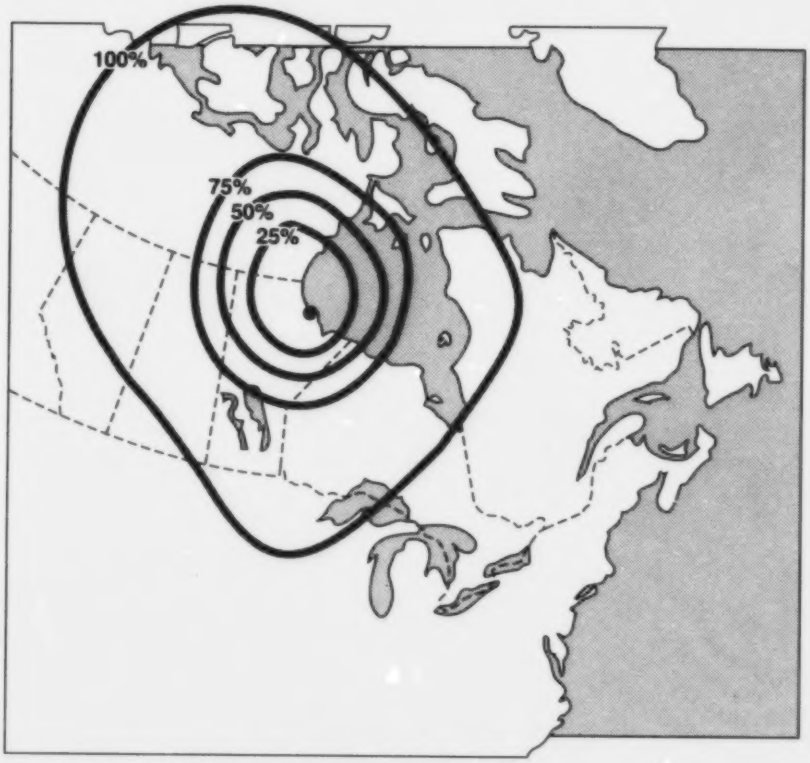


wet NH_4^+ deposition

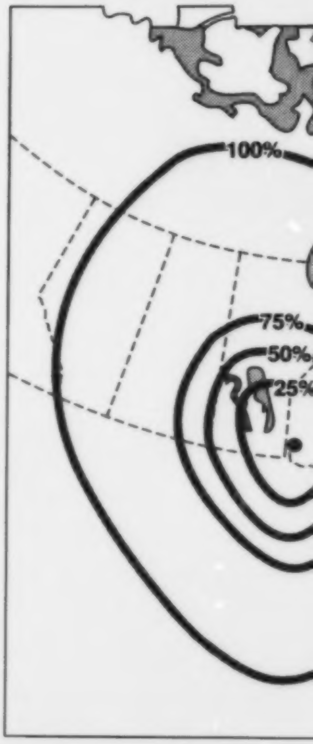
0.20 deposition of ion (kg/ha/yr)

extrapolation through data sparse areas

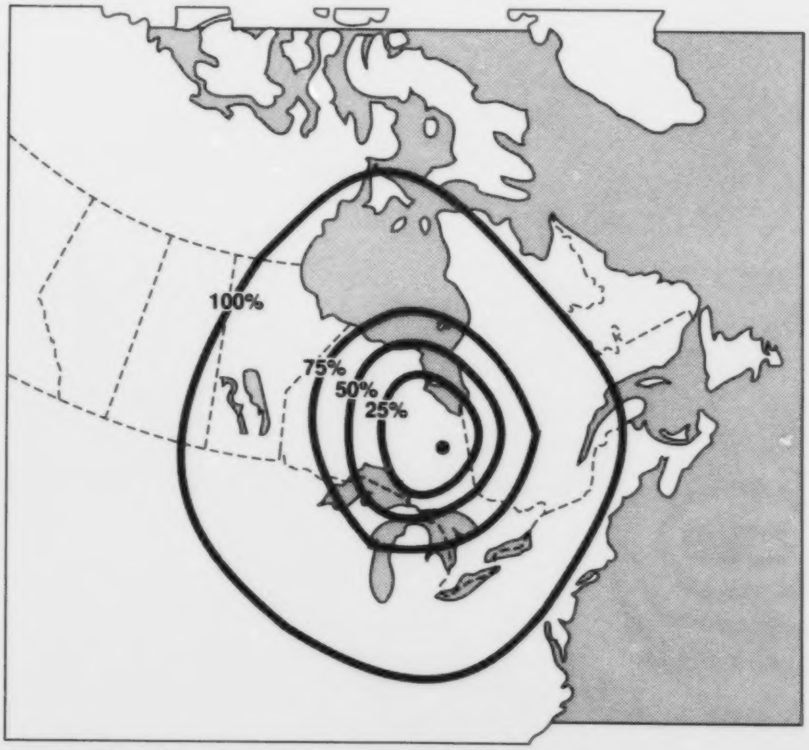
Source:
Atmospheric Environment Service, Natchem



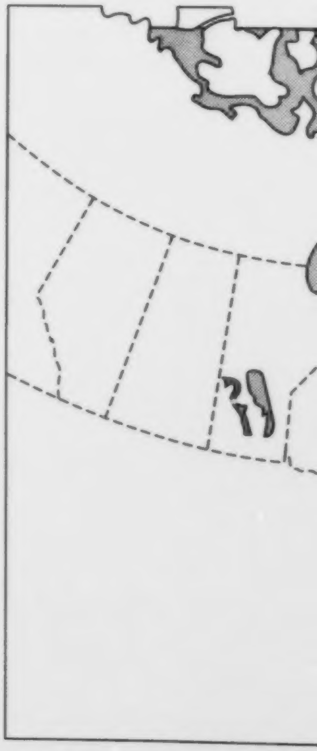
One-day travel distance from Churchill



One-day travel distance fro



One-day travel distance from Fraserdale

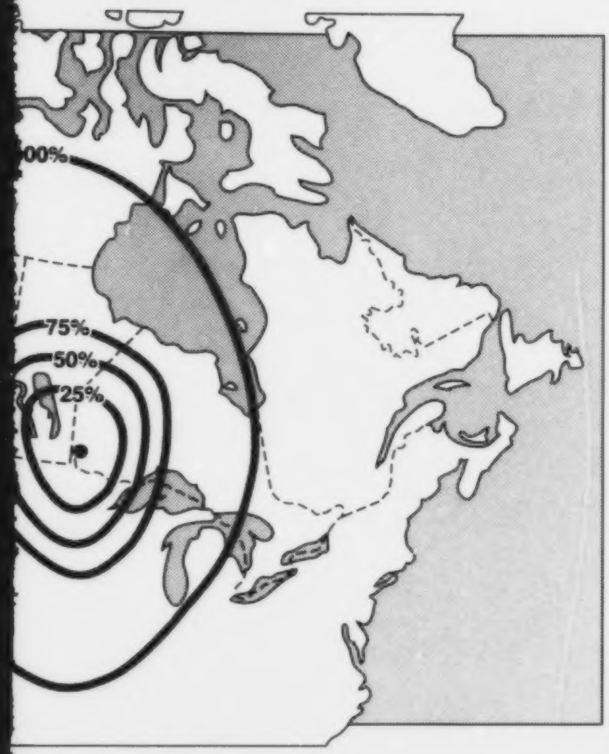


One-day travel distance fro

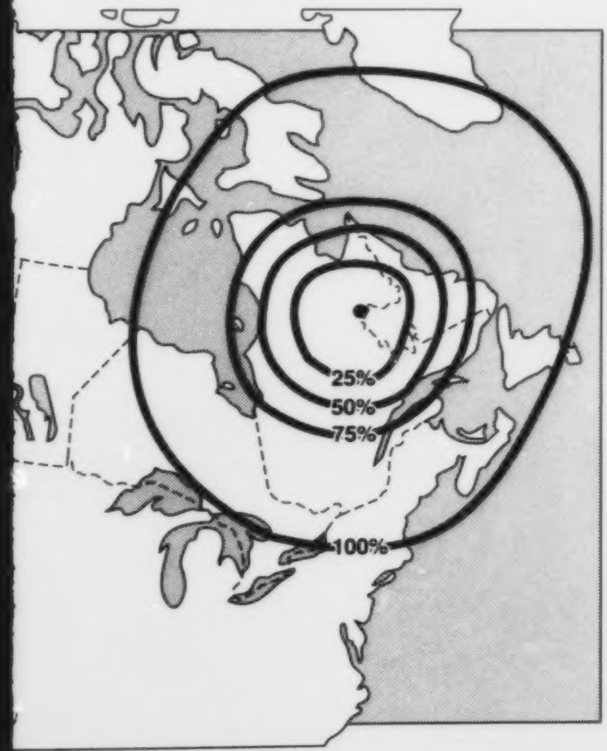
map 2.4.3

NORTHERN WETLANDS STUDY AREA

Atmospheric regions of influence (AROI) for 1-day travel distance of air

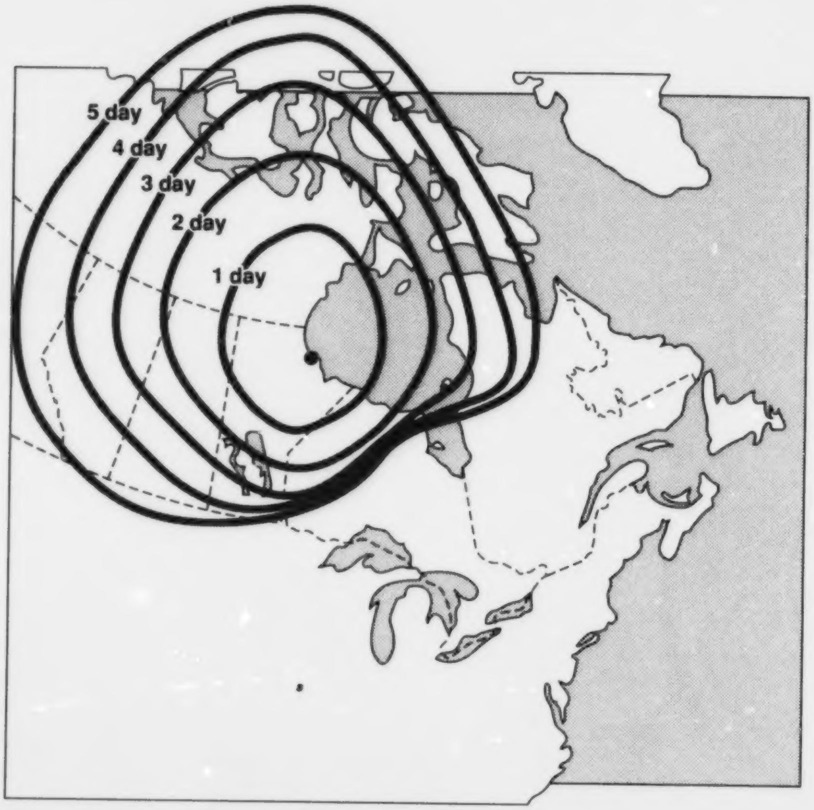


ance from ELA-Kenora

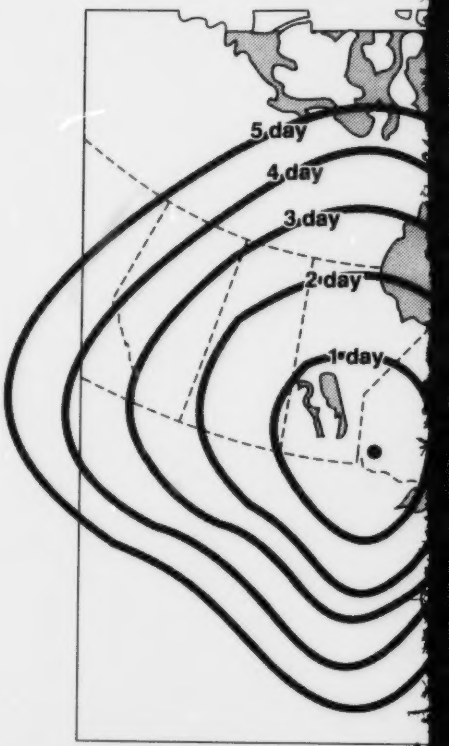


ance from Schefferville

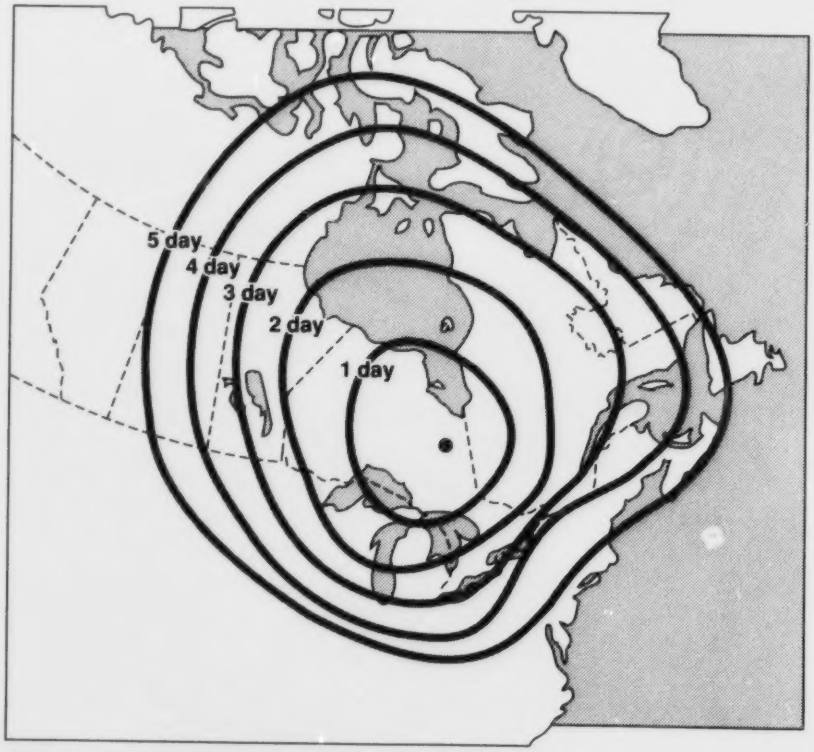
100%	Lines enclose locations of the starting points for air 1 day prior to arriving at each site. The 50% (or median line) indicates that half of the time the air originated within this line. The 100% (or maximum) line encloses all cases and, therefore, defines the outer limit of the one-day AROI. Based on 9 years (1979 to 1987) of meteorological data.



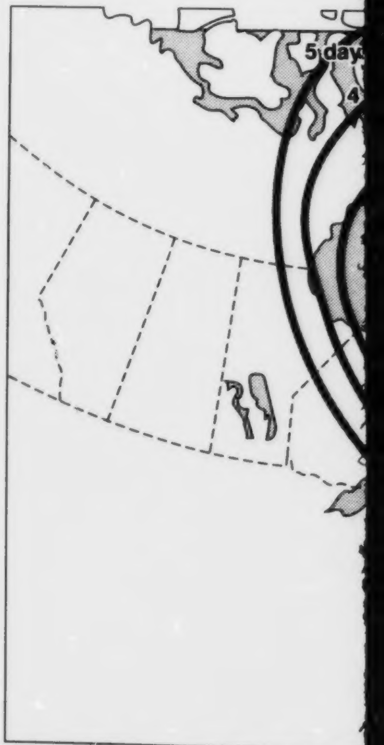
Travel distances from Churchill



Travel distances from ELA-Ke



Travel distances from Fraserdale



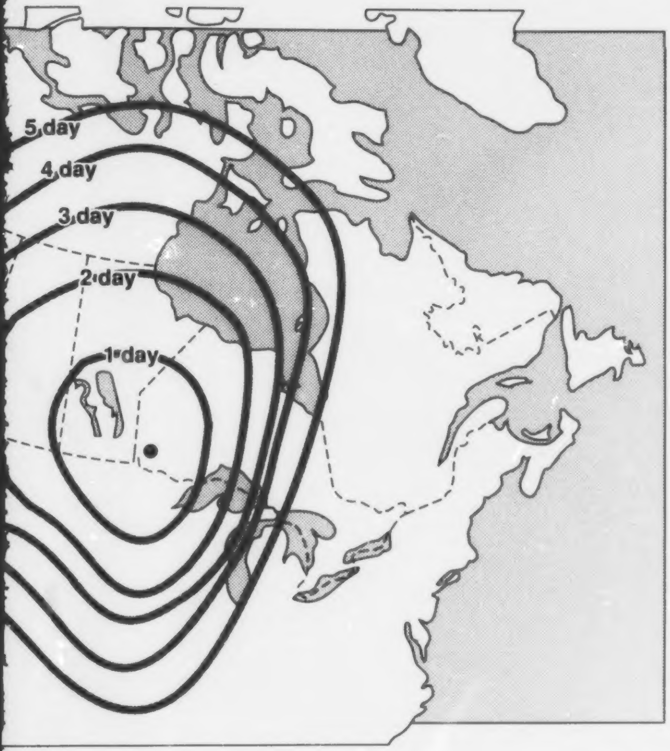
Travel distances from Scheffer

map 2.4.4

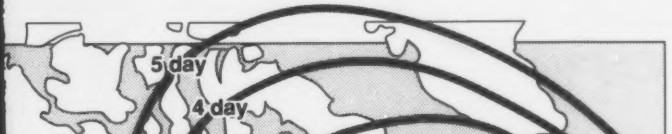
NORTHERN WETLANDS STUDY AREA

Most probable atmospheric regions of influence for 1 to 5 days

1 day median travel times (days),
based on 9 years of meteorological data
1979 to 1987.



ces from ELA-Kenora



ces from Schefferville

The patterns for the other 3 sites are also shown in Map 2.4.4. Again, there is a general similarity between sites although as the travel times increase substantial differences appear. For example, travel distances to Churchill from the southeast sector tend to be very short and the pattern at ELA has shorter distances from the southwest than from either the west or south.

2.4.3 DIRECTION OF AIR-MASS ARRIVAL

In terms of the long-term impact of a pollution source within the AROI, not only is the travel distance (or time) important, but also the frequency with which the air arrives from a given sector. Map 2.4.5 shows the frequency distribution of arrival from the various sectors for one and five days at Fraserdale. For one-day travel, the air originates in the west, northwest or north sectors 62 percent of the time, with the highest frequency, 24.7 percent, in the northwest sector. As the travel time increases, the frequencies for a west or southwest origin decrease, but the frequencies of a northwest or north origin increase to the point where the air originates in the northwest or north sector five days earlier 2/3 of the time. This shift in frequencies is due to the predominating cyclonic curvature of air flows in these latitudes.

The other 3 sites, shown in Map 2.4.5, all show similar frequency distributions. Churchill has the highest frequency of northerly-originating-air 5 days back and Schefferville the highest frequency for northwesterly-originating-air 5 days back.

2.4.4 SEASONAL VARIATIONS IN AIR MOVEMENT

For a one-day travel time, there is little seasonal variation in the spatial pattern of the percentiles for travel distances.

For a five-day travel time to Fraserdale, there is still little significant difference in the median travel distance in most sectors as shown in Map 2.4.6. The biggest difference is in the easterly sector where the median travel distance in the winter is twice that in summer. However, the frequency of occurrence of arrival from the east is very low at only 2 percent in both summer and winter.

Considering all directional sectors, the seasonal changes are rather small with an overall tendency for the frequency of arrival from the north and northwest sectors to be slightly higher in winter than in summer, and from the west, southwest and south sectors to be considerably higher in summer than in winter.

2.4.5 CONCLUSIONS

The results presented on travel distance over various time periods are interesting from a strictly meteorological point of view. However, the practical application of a region of influence for the potential impact of pollutant sources on a given receptor (i.e., the Northern Wetlands Study area) requires, among other things, knowledge of the lifetime of the pollutant in the atmosphere. While we have good information for some pollutants, especially the various sulphur species, less is known on the lifetimes of others such as nitrogen species. For many of the priority toxic chemicals, very little is known.

The typical residence time for sulphate in mid-latitudes is 3-5 days. The isopleths for 5 days travel time at Fraserdale (Map 2.4.6) from the south and southwest sectors just reach the major SO_2 and NO_x pollution sources in the Ohio Valley region in the summer, spring and fall. In winter, the 5-day travel time, extends only as far south as the lower Great Lakes. The frequency of arrival from these combined south and southwest sectors, 5 days back in time, is only 4.4 percent in winter, 7.1 percent in spring, 10.6 percent in summer and 10.5 percent in fall. These numbers, therefore, represent the maximum probability of pollution episodes originating in the Ohio Valley reaching Fraserdale in the absence of scavenging by intervening rainfall. Elevated man-made pollution levels at Fraserdale could occur up to 3 days a month in the summer and fall and the remainder of the time low background levels will predominate.

2.4.6 REFERENCES

Atmospheric Environment Service NATCHEM, National Atmospheric Chemistry Data Base. Atmospheric Environment Service, Downsview, Ontario.

Summers, P.W. and Young, J.W.S. 1987. The "Airshed" or "Atmospheric Regions of Influence" for the Great Lakes basin. Presented at the IJC Symposium "Towards Integrated Monitoring—A Great Lakes Perspective", Toledo, Ohio, 18 November, 1987.

U.S. Environmental Protection Agency. 1989. The 1985 NAPAP emissions inventory (version 2): Development of the annual data and modellers' tapes. Prepared for the National Acid Precipitation Assessment Program by the Air and Energy Engineering Research Laboratory, U.S. EPA Report #EPA-600/7-89-12a, Research Triangle Park, NC.

2.5 PHYSIOGRAPHY, BEDROCK GEOLOGY AND SURFICIAL GEOLOGY

2.5.1 RELIEF

Within the Northern Wetlands Study area elevation varies from sea level along the Atlantic and Hudson Bay coasts to a maximum of between 900 and 1,200 m in southeastern Labrador (Map 2.5.1). The highest elevation is 1,189 m which occurs in the Mealy Mountains located east of Goose Bay, Labrador. This area is very rugged with steep scarps occurring along the north and east sides of the mountain complex.

South and west of Hudson Bay, the land rises extremely gradually. Maximum elevations in the Manitoba and Ontario portions of the study area are between 300 and 600 m. The terrain is flat to gently rolling with rugged topography restricted to the north shore of Lake Superior. The highest elevation in Ontario, Tip Top Mountain (636 m), lies just south of the study area to the east of Lake Superior.

2.5.2 PHYSIOGRAPHY

Physiographic Regions and Divisions of Canada have been defined by Bostock (1970). Regions are defined primarily on the basis of broad geological structure whereas Divisions are based on sub-regional physiography (mountains, plateaux, plains and hills). The Northern Wetlands Study area consists of six physiographic Regions which are subdivided into 23 Divisions (Map 2.5.2).

2.5.2.1 JAMES REGION (J)

The James Region is the largest physiographic region and consists of 11 Divisions within the study area (Map 2.5.2). Most physiographic divisions of this region are characterized by gently rolling to broken uplands formed on the crystalline granitic rocks of the Canadian Shield. These areas have numerous small lakes and wetlands occurring in bedrock depressions. Surface runoff tends to be poorly organized and is characterized by numerous lakes connected by short rapid streams and rivers.

Generally, this type of bedrock-controlled topography is not suitable for the development of large wetland complexes. The largest wetland areas occur where clays and silts overlie the bedrock. Within the James Region, these conditions are found on the glaciomarine deposits of the Eastmain Lowland (J-11) and glaciolacustrine sediments of the southwest Severn Upland (J-5) and north-central Abitibi Upland (J-8).

The highest elevations in this region occur in the Lake Plateau (up to 910 m; J-13), Kaniapiskau Plateau (greater than 910 m; J-14) and Mistassini Hills (greater than 1,070 m; J-12).

The Nipigon Plain (J-6) and Labrador Hills (J-15) Divisions are different than the typical Canadian Shield topography of the other divisions within this region. The first consists of a flat bedrock plain with deep river valleys and the latter consists of a series of ridges and valleys formed due to strong folding of the bedrock. Wetlands are restricted to the low-lying areas in valleys and along rivers.

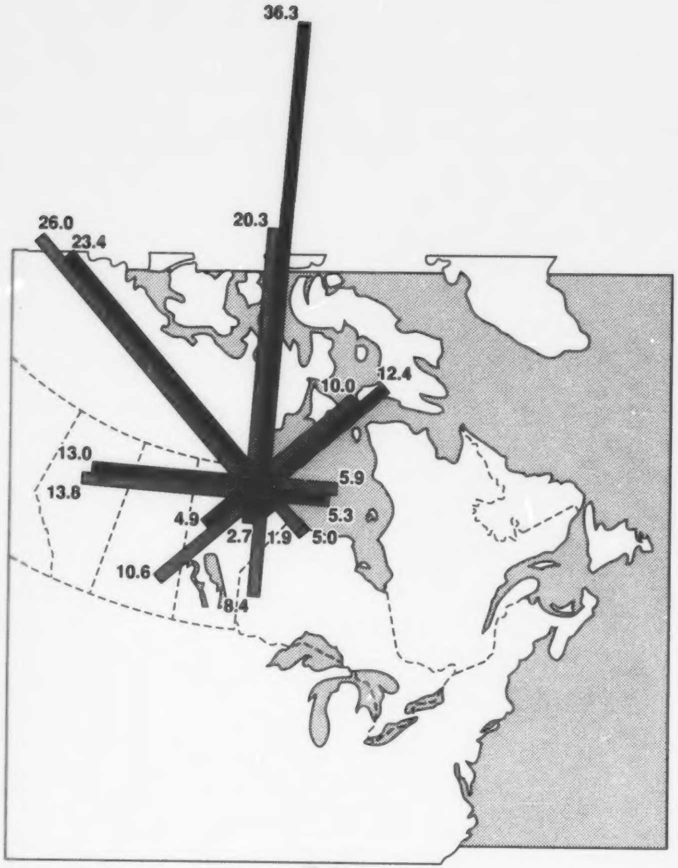
2.5.2.2 HUDSON REGION (H)

The Hudson Region is composed of the Hudson Bay Lowland (H-3) and Richmond Hills (H-4) Divisions. The latter is not of any consequence in terms of wetland development.

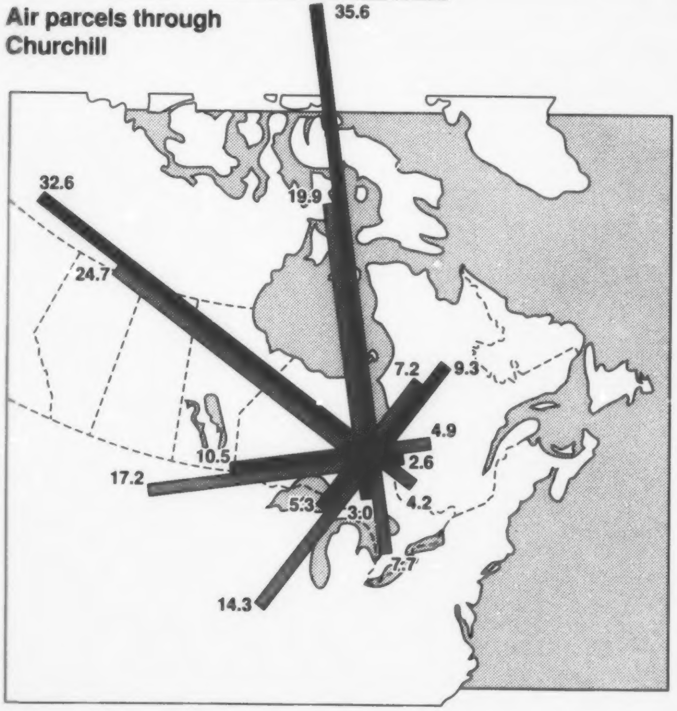
The Hudson Bay Lowland is a large coastal plain adjacent to Hudson and James Bays. Wetlands occupy between 85 and 90 percent of its surface (Riley 1982). Ideal conditions for wetland development in this area include a flat topography with a very gentle slope and impermeable substrates consisting of fine-grained glaciomarine clays and silts. The coastal plain rises from sea level to about 150 m above sea level where it meets the Canadian Shield. Surface gradients range between 0.6 and 1.0 m/km (Riley 1982). The Sutton Ridges, located in the Lowland southeast of Peawanuck, form the only major relief component of the entire region. They consist of bedrock hills which rise up to 200 m above the surrounding wetland plain.

The Hudson Bay Lowland is the second largest unconfined peatland in the world (Section 1.2). Wetlands are interrupted only by large rivers which drain into Hudson and James Bays. Surface runoff consists of non-channelized seepage flow in peatlands which feed a network of parallel and relatively straight channels connecting to major rivers such as the Churchill, Nelson, Severn, Winisk, Attawapiskat, Albany and Moose Rivers.

Wetland development in this region is controlled predominantly by isostasy, hydrology and nutrient status. The Lowland is uplifting at a rate of about 1 m/100 years due to isostatic rebound. Hence, wetlands nearest the coast are up to 7,000 years younger than those adjacent to the Canadian Shield. Younger wetlands and those located in seepage areas tend to be minerotrophic due to contact with groundwater which



Air parcels through
Churchill

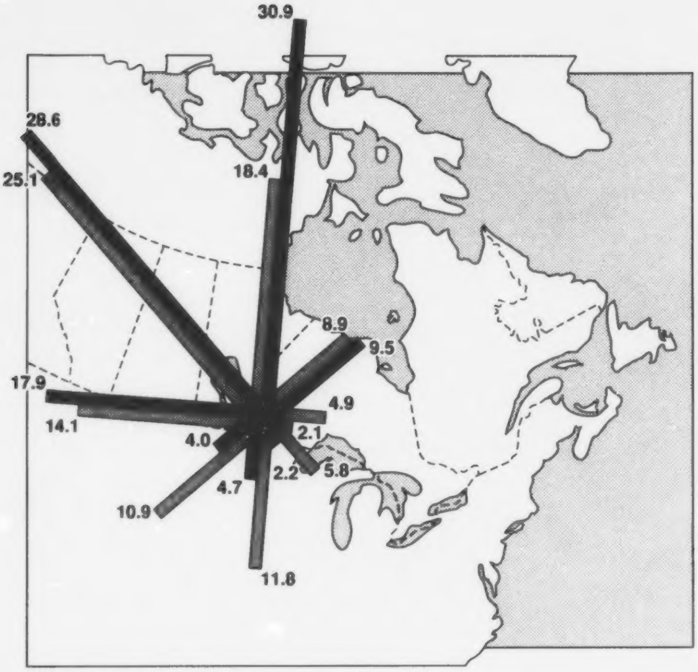


Air parcels through
Fraserdale

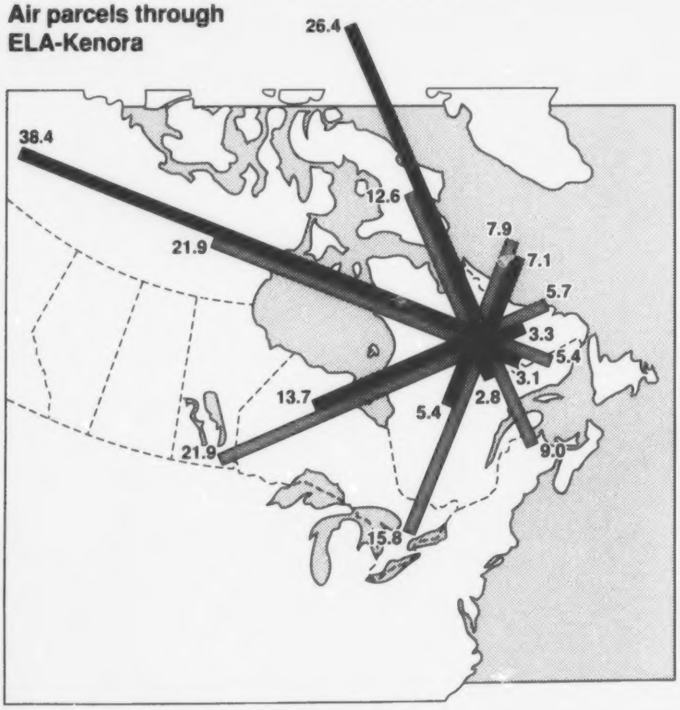
map 2.4.5

NORTHERN WETLANDS STUDY AREA

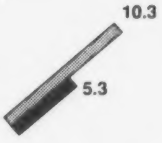
The frequency of occurrence of the origin of air parcels for one day and five days back in time stratified by the eight directional sections.



Air parcels through ELA-Kenora

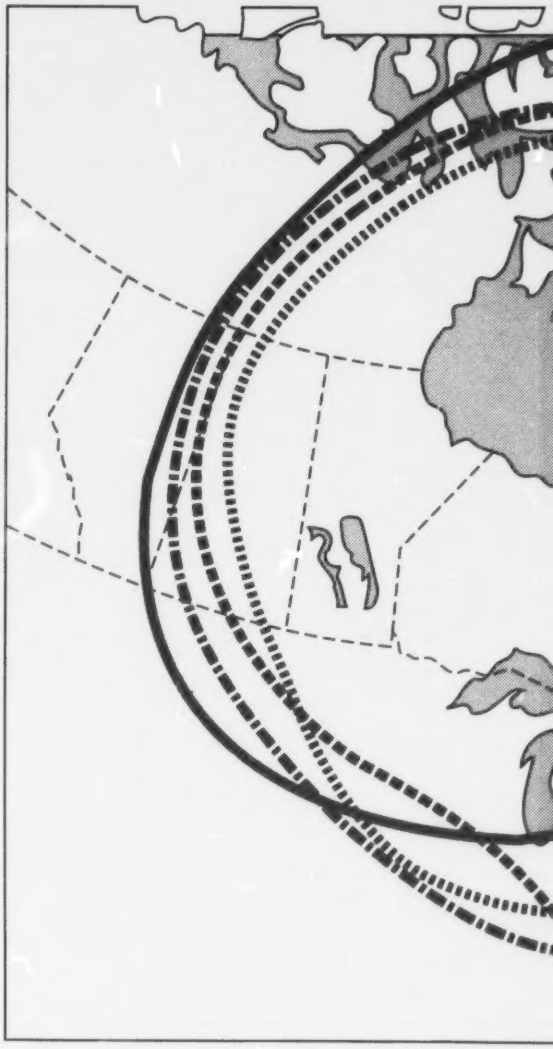


Air parcels through Schefferville



10.3 direction of origin and frequency of occurrence over 1-day period

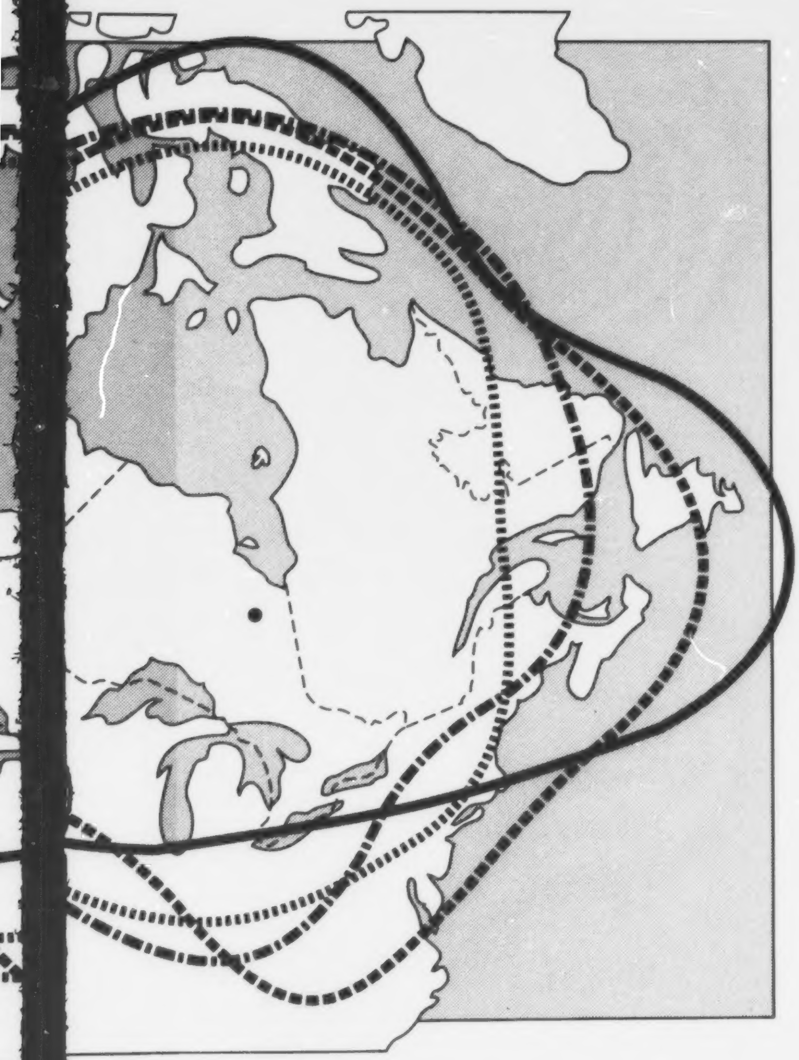
5.3 direction of origin and frequency of occurrence over 5-day period



map 2.4.6

NORTHERN WETLANDS STUDY AREA

Seasonal variations in the five day median travel distance of an air parcel to Fraserdale

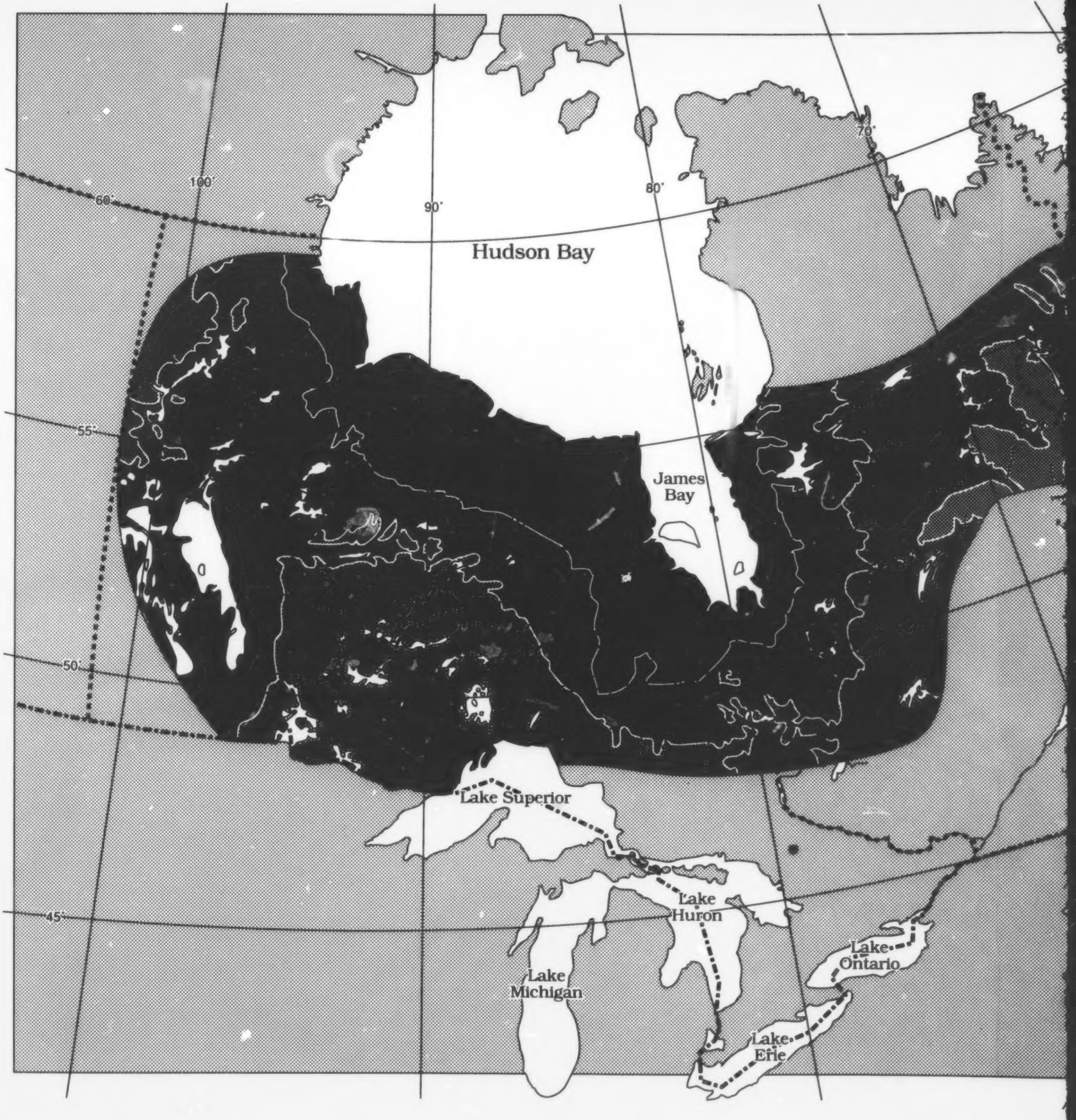


winter

spring

fall

summer

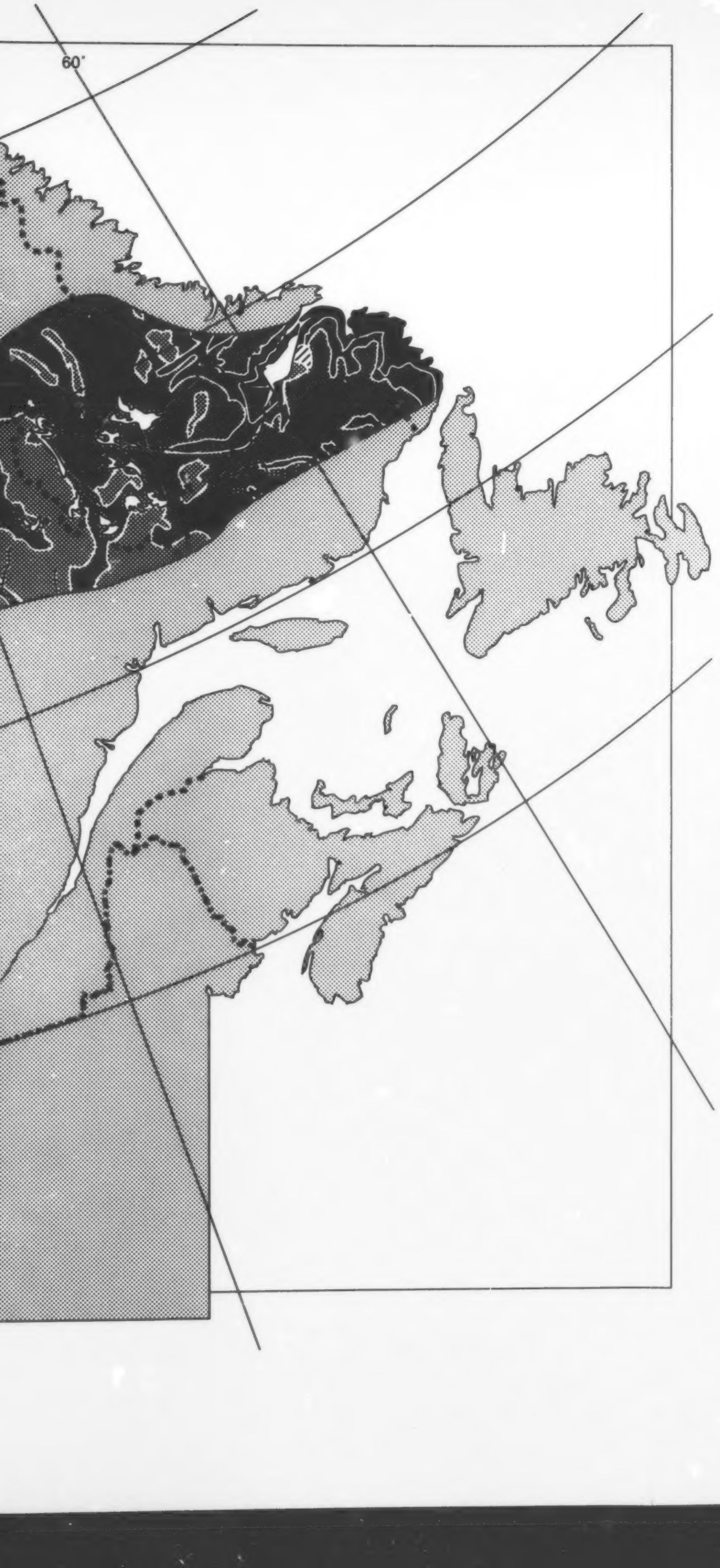


Hudson Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°

map 2.5.1

NORTHERN WETLANDS STUDY AREA

Generalized Relief



Elevation range (metres above mean sea level)

■ 0 - 150

■ 150 - 300

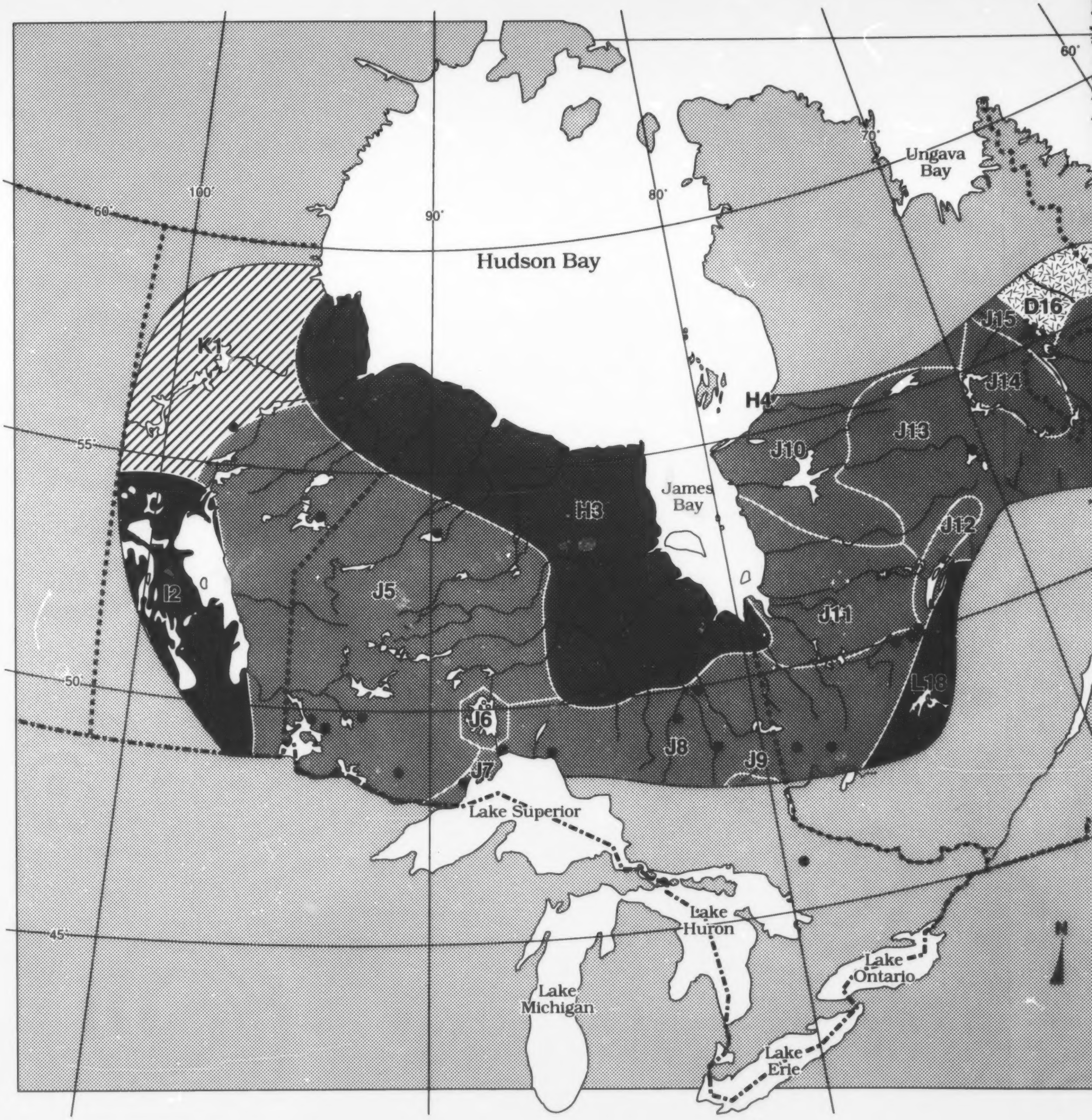
▩ 300 - 600

▒ 600 - 900

▨ 900 - 1,200

Source:
Relief, 1:12.5 m, National Atlas of Canada
(Energy, Mines & Resources, 1974)

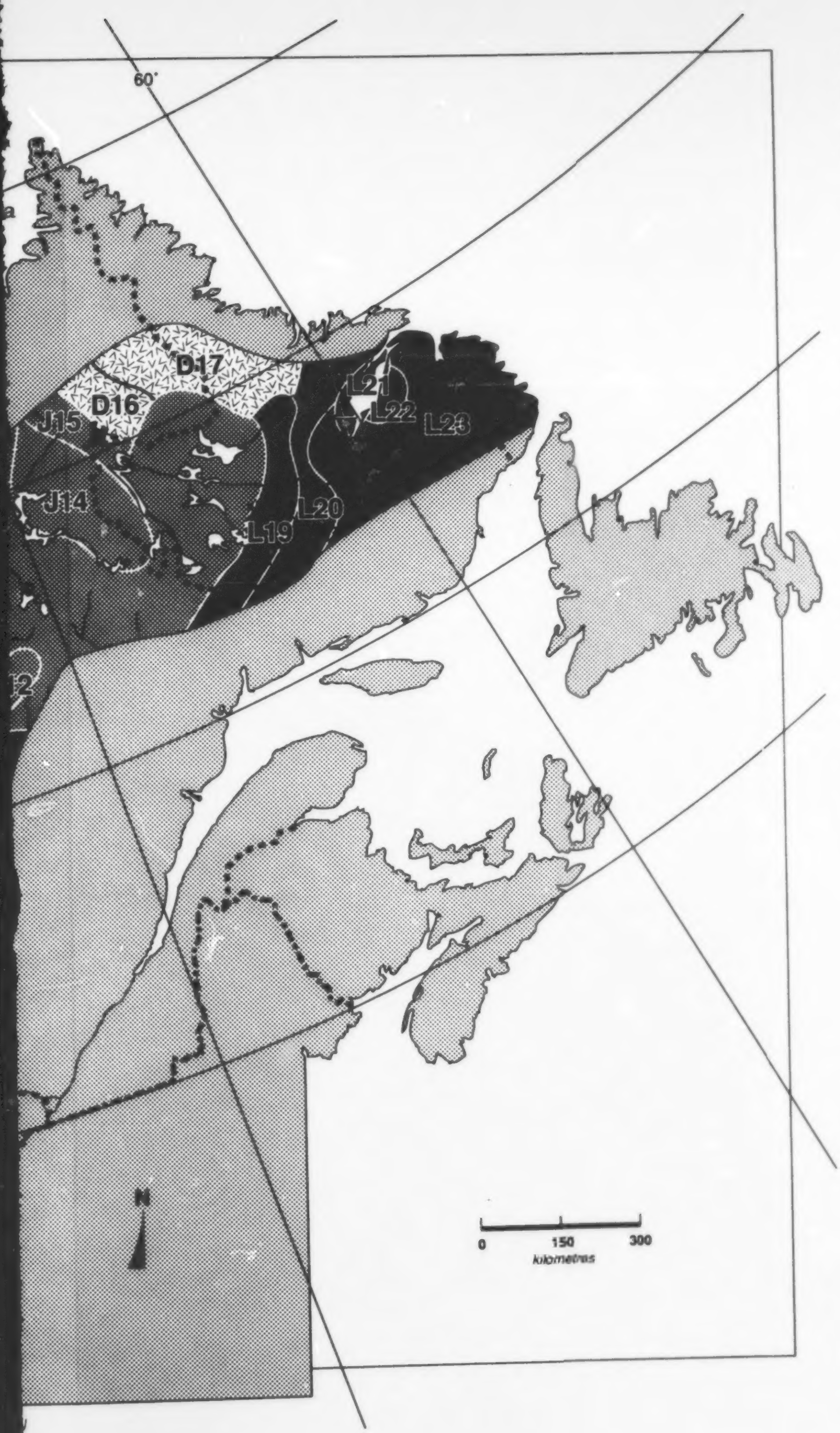
Projection: polar stereographic


60°
Ungava Bay
70°
100°
80°
90°
60°
Hudson Bay
D16
J15
K1
J14
H4
J13
55°
J10
James Bay
H3
J12
I2
J5
J11
50°
L18
J6
J8
J9
J7
Lake Superior
Lake Huron
45°
N
Lake Ontario
Lake Michigan
Lake Erie

map 2.5.2

NORTHERN WETLANDS STUDY AREA

Physiographic Regions & Divisions



	Region		*Division*
▨	**Kazan Region**	K1	Kazan Upland
■	**Interior Plains**	I2	Manitoba Plain
▩	**Hudson Region**	H3	Hudson Bay Lowland
		H4	Richmond Hills
▒	**James Region**	J5	Severn Upland
		J6	Nipigon Plain
		J7	Port Arthur Hills
		J8	Abitibi Upland
		J9	Cobalt Plain
		J10	Larch Plateau
		J11	Eastmain Lowland
		J12	Mistassini Hills
		J13	Lake Plateau
		J14	Kaniapiskau Plateau
		J15	Labrador Hills
▧	**Davis Region**	D16	Whale Lowland
		D17	George Plateau
■	**Laurentian Region**	L18	Laurentian Highlands
		L19	Hamilton Upland
		L20	Hamilton Plateau
		L21	Melville Plain
		L22	Mealy Mountains
		L23	Mecatina Plateau

Source:
Physiographic Regions of Canada, 1:5 m.
(Energy, Mines & Resources, 1970)

Projection: polar stereographic

has been enriched by nutrients from the base-rich sediments. Nutrient-poor ombrotrophic wetlands are common along drainage divides and where peat accumulation raises the surface of the peatland sufficiently to isolate the living community from the minerotrophic groundwaters.

2.5.2.3 LAURENTIAN REGION (L)

The Laurentian Region is the third largest physiographic region in the study area. It consists of 6 Divisions, 5 of which occur in the easternmost portion of the Northern Wetlands Study area. This Region is characterized by uplands and highlands rising abruptly from the St. Lawrence Lowland to the south and Atlantic Ocean to the east. The boundaries of the Laurentian Region are characterized by strong relief as a result of fault scarps (Bostock 1972). This contrasts sharply with other portions of the Canadian Shield which gradually dip beneath the sedimentary strata of the Interior Plains and Hudson Bay Lowland.

The Laurentian Region has the most rugged topography and highest elevations (Mealy Mountains Division; L-22) of the study area. The surface of the uplands and plateaux are commonly between 300 and 600 m above sea level. Runoff from these areas drains rapidly into large rivers which have deeply dissected the bedrock-controlled topography.

Wetlands, particularly bogs, are abundant in this region even though it tends to be rugged. Large areas covered by glacial till, broad river valleys and low-lying marine plains within the region have widespread organic terrain. Wetlands are most common in the Melville Plain (L-21), which is a lowland occurring near sea level; the eastern and central portions of the Mecatina Plateau (L-23), which is primarily a till covered rolling plateau; and along the broad river valleys and drumlinized terrain characteristic of the Hamilton Upland (L-19) and Hamilton Plateau (L-20).

2.5.2.4 KAZAN REGION (K)

The Kazan Region consists of only one Division (Kazan Upland; K-1) within the study area. The topography is gently rolling with numerous lakes and sporadic wetlands. This region occupies the Canadian Shield and is physiographically similar to the Severn and Abitibi Divisions (J-5 and J-8) of the James Region.

2.5.2.5 DAVIS REGION (D)

The Davis Region includes the Whale Lowland (D-16) and the George Plateau (D-17). The Whale Lowland has a greater expanse of wetlands than the George Plateau. Wetlands cover between 26 and 50 percent of the lowland which is a large drift covered (glacial till) plain. Bedrock exposures occur mainly as scattered hills, generally less than 600 m in elevation. The Lowland is drained by the Whale River which flows into Ungava Bay.

The George Plateau is a large upland which is deeply dissected by valleys. Rivers drain northward into Ungava Bay. The plateau rises gradually in elevation from the Whale Lowland in the west toward the mountain ranges of the Labrador coast (Labrador Highlands) outside the study area. The highest parts of the plateau are between 300 and 600 m elevation. It is primarily a massive bedrock-controlled plateau with till occurring in low-lying areas. Wetlands are restricted to river valleys and areas of till. They occupy 25 percent or less of the George Plateau.

2.5.2.6 INTERIOR PLAINS REGION (I)

The extreme southwestern portion of the Northern Wetlands Study area is represented by the Manitoba Plains Division (I-2) of the Interior Plains Physiographic Region. This is a flat-lying area consisting predominantly of glaciolacustrine clays and silts of glacial Lake Agassiz. The clays overlie glacial till which, in turn, overlies sedimentary rocks. The average elevation of the Manitoba Plain is about 240 m above sea level. Drainage consists of abundant lakes and large slow-flowing rivers such as the Red, Assiniboine and Saskatchewan Rivers. Open water covers almost 50 percent of the surface of this plain mostly as large lakes such as Lakes Winnipeg, Winnipegosis and Manitoba. Fine-grained sediments common to this inter-lake area, along with a flat topography, results in poor drainage and the development of wetlands. Wetlands occupy from 26 percent to over 75 percent of the area.

2.5.3 BEDROCK GEOLOGY

The bedrock geology (Map 2.5.3) of the Northern Wetlands Study area is characterized by three major geological components. The largest, oldest and most dominant is the Canadian Shield. The Shield covers over 70 percent of the map area extending in a broad semi-circle from the extreme northwest to the coast of Labrador. It is composed predominantly of massive crystalline rocks such as granite (igneous rocks) and granitic gneiss (metamorphosed granites). These rocks are referred to as acid rocks because of their enrichment in quartz as compared to the base-rich minerals.

The other two major geological components of the study area are the Interior Platform and the Hudson Platform. These are deep basins which are characterized by well-bedded sedimentary rocks including a large proportion of calcareous rocks such as limestone. The basins represent depressions in the Canadian Shield (which continues beneath them) in which large accumulations of silts, clays, sands and lime were deposited from marine seas which spread over most of central North America beginning about 500 million years ago.

2.5.3.1 CANADIAN SHIELD

The Canadian Shield is the main geological building block of the North American Continent. It is composed mostly of crystalline metamorphic and igneous rocks of Precambrian age including some of the oldest rocks in the world. Bedrock of the Shield underwent several periods of mountain building (tectonics) over 500 million years ago. Since that time tectonic activity has been very minor and the Shield has been subjected to weathering.

The Canadian Shield is subdivided into nine structural provinces five of which occur within the map area: Churchill, Superior, Southern, Grenville and Nain Provinces (Figure 2.5.1). Differences among the provinces are based primarily on structural features such as faulting and folding and on the age of the tectonic event.

Each province represents a sequence of sedimentary and volcanic deposition into a large geosyncline (basin) at the edge of an earlier continent. These deposits were subsequently uplifted into large mountain systems and then eroded to their present form. During the mountain building event, the original rocks were deformed and metamorphosed resulting in the development of folds and faults and changes in rock type.

Superior

This is the oldest of the Shield Provinces, with isotopic dating indicating an age of about 2.5 billion years for the last tectonic event. It is also one of the largest of the structural provinces of the Shield and composes over 80 percent of the Precambrian rocks of the map area.

The bedrock consists of long, easterly trending belts of metamorphosed and folded sedimentary and volcanic rocks separated by predominantly granitic rocks. The sedimentary and volcanic rocks are predominantly base-rich in comparison to the surrounding acid granite and granite gneiss.

Churchill

The Churchill Province is the largest province of the Canadian Shield and the second largest of the map area. It is found in Manitoba and along the Québec—Labrador Border. The last tectonic event occurred approximately 1.6 billion years ago.

Bedrock of the Churchill Province is similar to the Superior Province with metamorphosed volcanic and sedimentary belts surrounded by granite and granite gneiss.

Southern

The Southern Province lies mostly within the northern U.S. It extends into Canada forming a very small portion of the map area along the northwest shore of Lake Superior (Figure 2.5.1). It formed at approximately the same time as the Churchill Province.

Within the map area, the bedrock is represented by flat-lying sedimentary and volcanic rocks which have not been metamorphosed. These include conglomerates, iron formations, argillite, taconite, limestone, chert, sandstone and thick basaltic lava flows. Gabbro and diabase intrusions cut through the older sedimentary and volcanic rocks.

This geological province is very distinct from the 'typical' Canadian Shield in rock type and structure (i.e., flat-lying, bedded rocks rather than massive crystalline rocks). The geological character of this area defines the extent of the Port Arthur Hills Physiographic Division (Map 2.5.2; J-7).

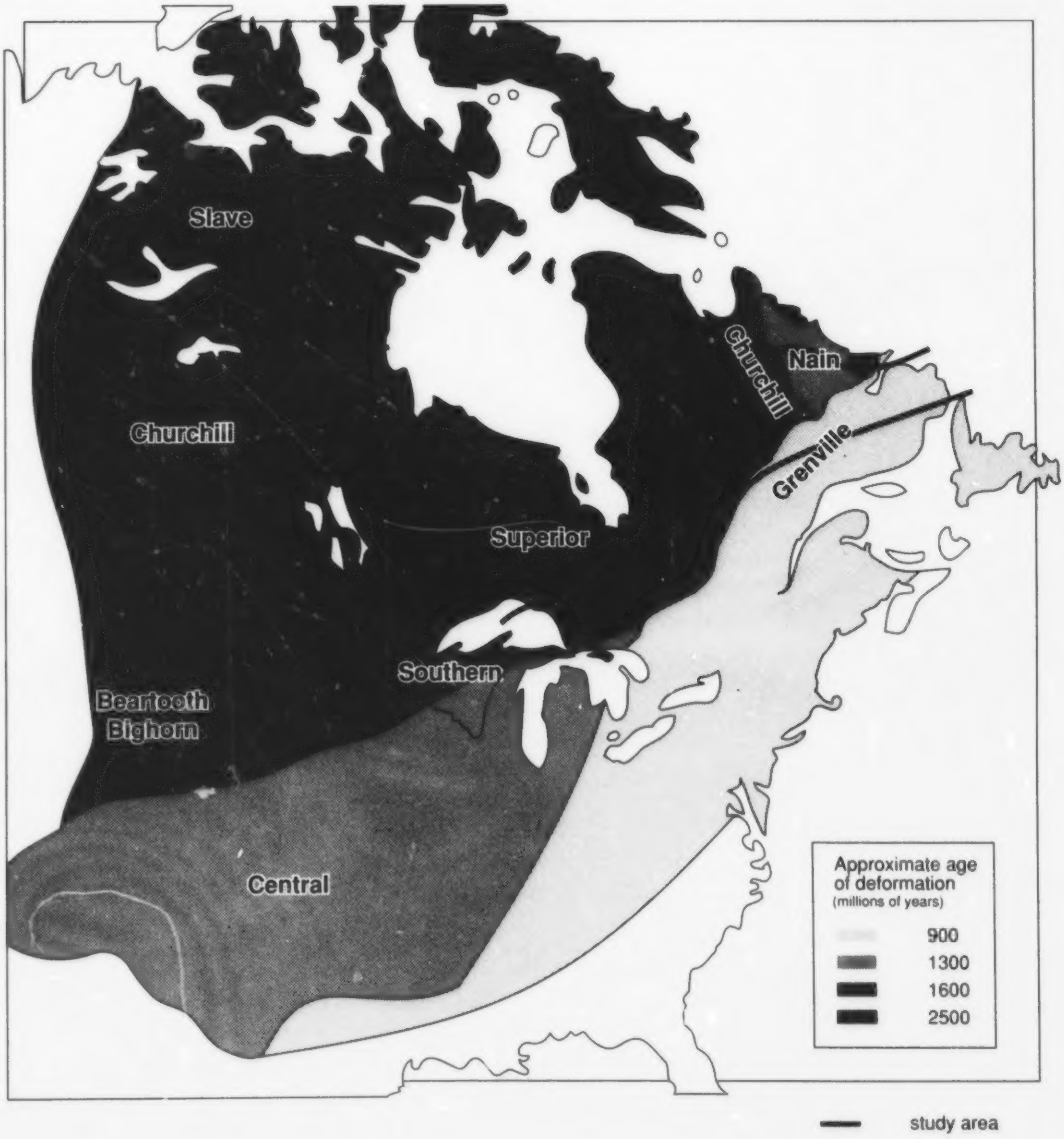
Nain

The Nain Province occupies most of northern Labrador (Figure 2.5.1). It formed approximately 1.3 billion years ago.

Structural trends in this province are northerly and abruptly truncate the northwest trends of the Churchill Province. The bedrock is a complex of folded, flat-lying and intrusive rocks. The most characteristic feature of this province is the large anorthosite (a variety of feldspar) intrusive masses. Other rock types include gabbro intrusives, metamorphosed volcanic rocks, granite and granite gneiss.

FIGURE 2.5.1

Structural provinces of the Precambrian in eastern North America showing the location of the Northern Wetlands Study area. Overlying Paleozoic sedimentary rocks are excluded (from Clark and Stearn 1968).



Grenville

The Grenville Province is the youngest at approximately 0.9 billion years. It truncates the Superior, Churchill and Nain Provinces along their southeast margin forming an abrupt boundary which is known as the Grenville Front. The Grenville Province occupies the southeast portion of the map area in Québec and southern Labrador (Figure 2.5.1).

Rocks of this province are highly metamorphosed with complex folding. Rock types reflect this strong metamorphic character with mica schist, granitoid gneiss, granulite, amphibolite, quartzite and marble (metamorphosed limestone) being most common.

2.5.3.2 INTERIOR PLATFORM

The Interior Platform forms the southwest portion of the map area in Manitoba and consists of rocks younger than Precambrian. It is an extensive geological unit of nearly horizontal sedimentary strata which forms the bedrock for the Interior Plains physiographic region (Map 2.5.2; I-2). It occupies the western portion of the Northwest Territories, the northeast tip of British Columbia, most of Alberta, southern Saskatchewan and southwestern Manitoba.

Within the map area, the geology consists of predominantly carbonates (limestones and dolomites) and evaporites (gypsum and anhydrite) of the Paleozoic including the Ordovician, Silurian and Devonian Periods. Overlying these are the younger Mesozoic (Jurassic Period) shale and sandstone. Large deposits of oil, gas and potash occur in the deeper sediments of this basin to the west of the map area.

2.5.3.3 HUDSON PLATFORM

The southern edge of the Hudson Platform in Manitoba, Ontario and Québec defines the extent of the physiographic region known as the Hudson Bay Lowland (Map 2.5.2; H-3 and Map 2.5.3). The bedrock is composed almost entirely of carbonates (limestone and dolomite, 55%) and siltstone (37%). Other rock types include sand, clay and lignite deposited during the Cretaceous Period (the youngest strata of the study area) and minor sandstone and gypsum. They range in age from about 450 million years to 65 million years.

Precambrian rocks of the Canadian Shield occur in a broad arc in the northeastern portion of the Lowland (rock types P-5). These Shield rocks form the Sutton Ridges which are composed of iron-rich rocks (iron formation) and crystalline igneous rocks (diabase, gabbro) where they outcrop. Their occurrence marks a thinning of the Hudson Platform in this area due to a high structural arch within the underlying Shield.

2.5.4 SURFICIAL GEOLOGY

Surficial geology relates to conditions of erosion and sedimentation at the upper surface of the bedrock. In most of Canada, including the study area, surficial landforms are primarily the result of a series of at least 4 major glaciations which occurred during the Pleistocene Epoch (from about 1 million to 10,000 years ago). Since the retreat of the last glaciers, erosion and sedimentation has been controlled by precipitation, freeze-thaw processes and gravity.

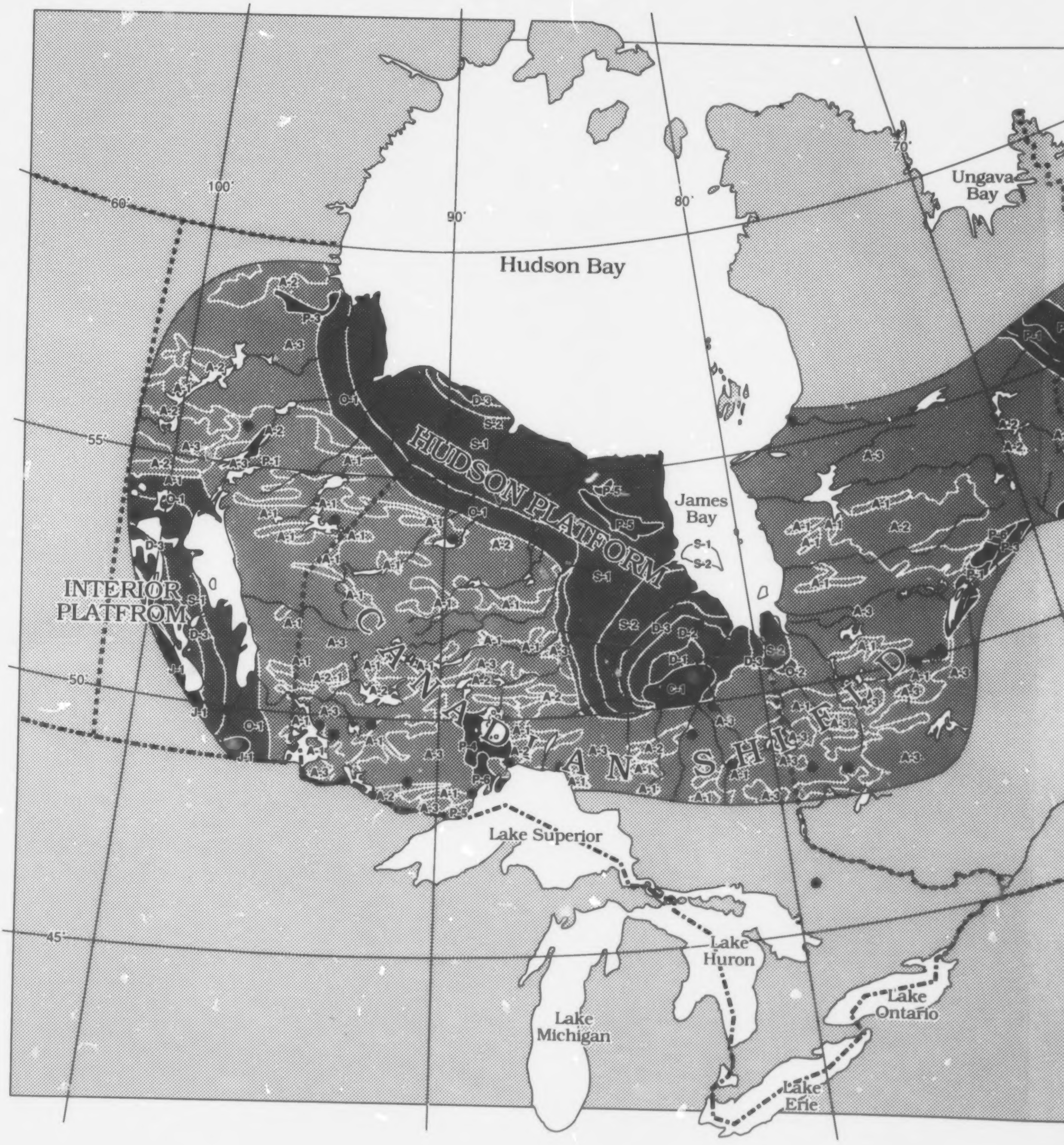
Features characteristic of glacial processes include scoured bedrock surfaces (erosional) and accumulations of various sediments deposited and shaped by glaciers' running waters (glaciofluvial), glacial lakes (glaciolacustrine) and higher sea levels (glaciomarine).

Glacial erosion was most intense on the relatively weak, stratified bedrock associated with the Hudson and Interior Platforms as compared to the massive crystalline rocks of the Canadian Shield. As a result, sedimentary rocks have contributed a great deal of detritus which was entrained in the advancing glaciers, forming extensive deposits. Such deposits tend to be fine-grained and base-rich reflecting the nature of the source rocks. The Canadian Shield rocks are resistant and weather to products which tend to be coarser and more acid.

Depositional features consist of: 1) poorly sorted tills including ground and terminal moraines, ablation till, and drumlins deposited directly by the ice; and 2) well-sorted and stratified deposits including outwash, eskers, lake and marine sediments. Within the study area, the largest and most continuous terminal moraines occur in Ontario northwest of Lake Superior. Drumlinized till plains are characteristic of north-central Manitoba and central Labrador.

Peat deposits are the most notable example of surficial deposits formed since glaciation. Other features are primarily the result of erosion and deposition by streams. They include river terraces, alluvial plains, lake and marine shorelines, slump forms and sand dunes.

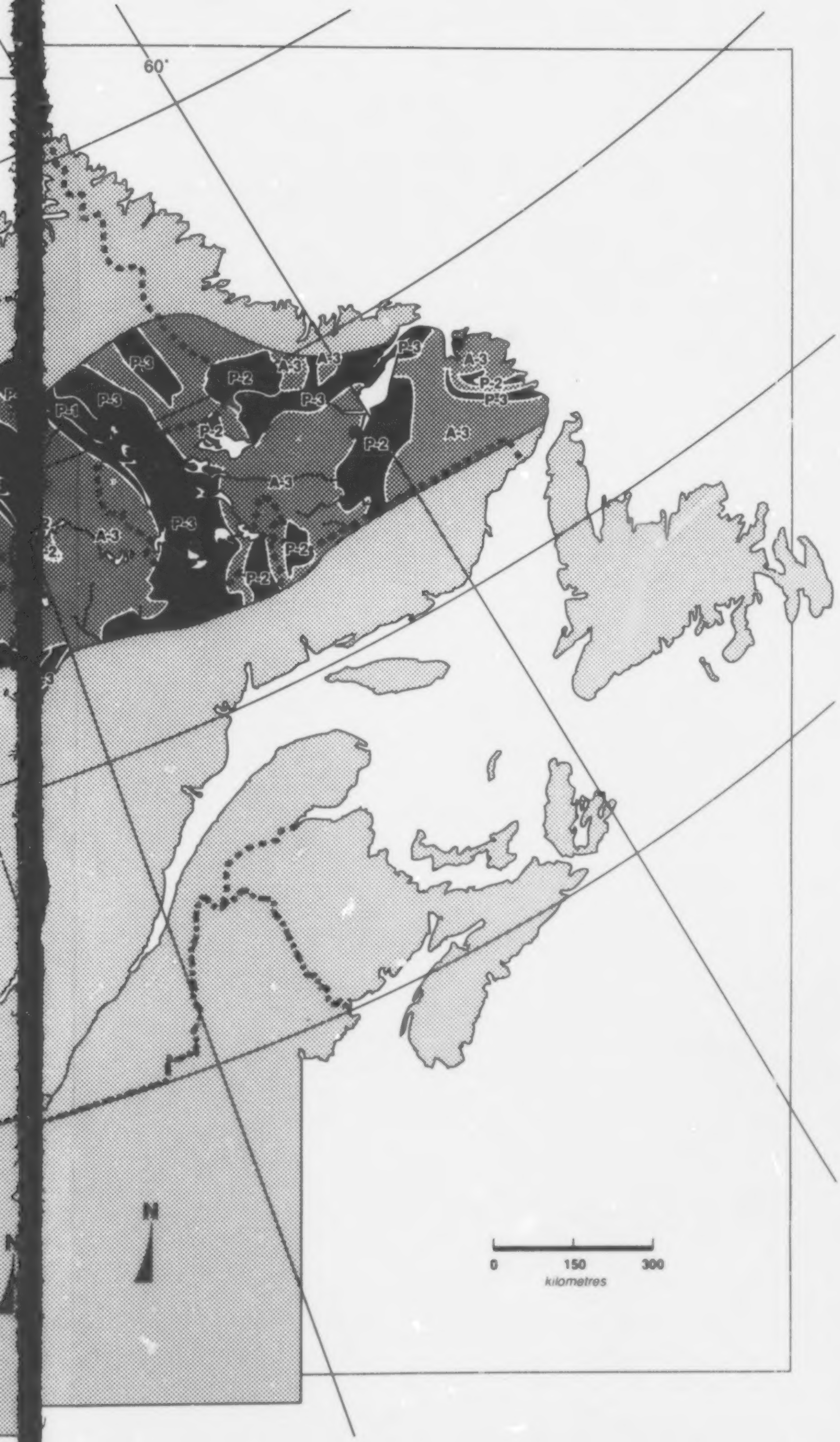
The surficial geology map (Map 2.5.4) identifies areas dominated by glaciomarine, glaciolacustrine and moraine (till) deposits as well as bedrock-controlled areas such as thin till and exposed bedrock. Glaciofluvial deposits such as eskers and kames are too restricted in extent to be shown on Map 2.5.4.


Hudson Bay
James Bay
Ungava Bay
HUDSON PLATFORM
CANADIAN SHIELD
INTERIOR PLATFROM
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
60°
55°
50°
45°
100°
90°
80°
70°
A-1
A-2
A-3
P-1
P-3
P-4
P-5
S-1
S-2
D-1
D-2
D-3
C-1
C-2
O-1
J-1

map 2.5.3

NORTHERN WETLANDS STUDY AREA

Bedrock geology



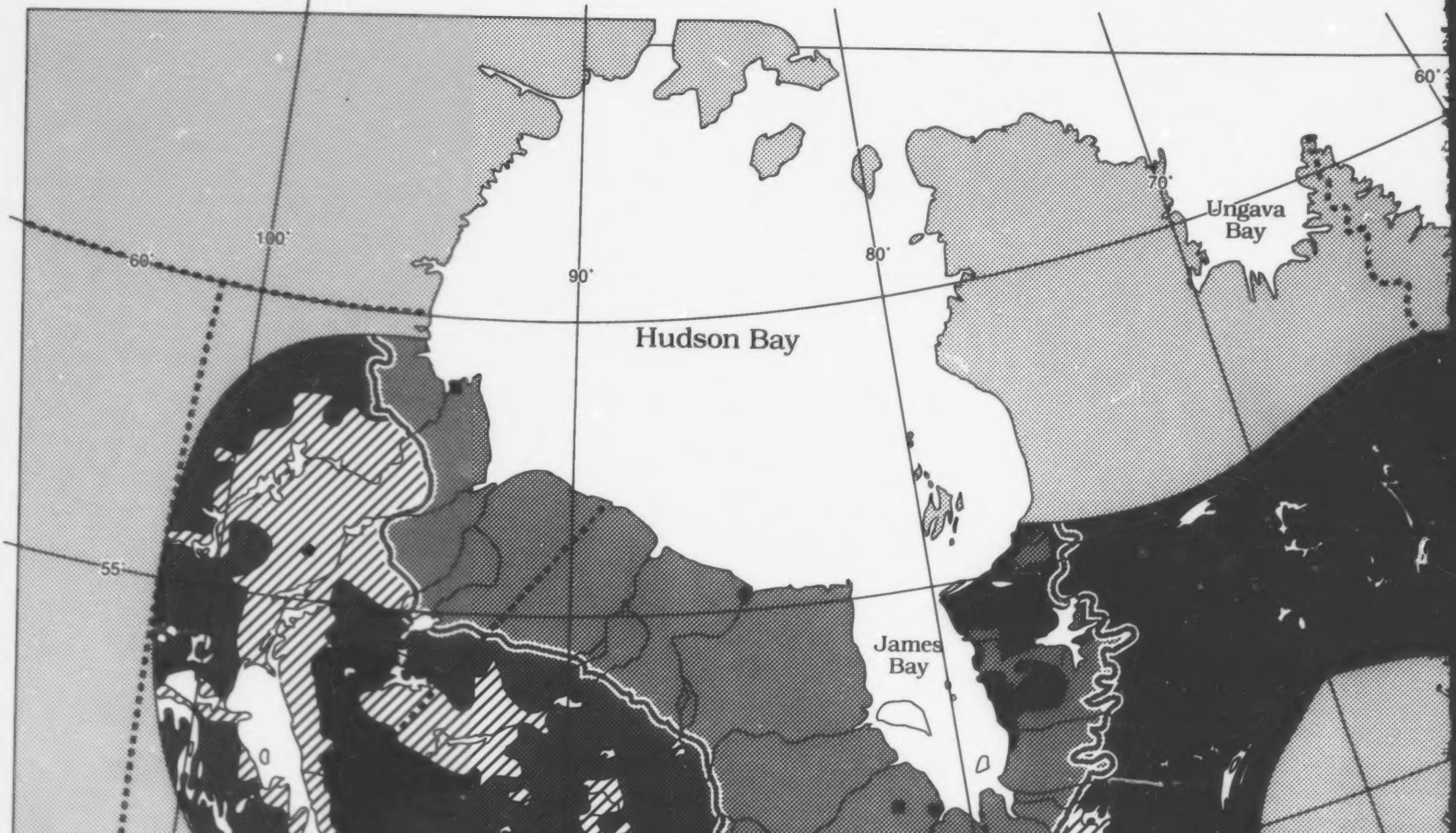
■	**Mesozoic**	Cretaceous	C 1	clays sands lignite
		Jurassic	J 1	sandstone shale
■	**Paleozoic**	Devonian	D 3	limestone shale sandstone conglomerate
			D 2	limestone dolomite shale gypsum
			D 1	black shale
		Silurian	S 2	limestone dolomite siltstone shale gypsum salt
			S 1	dolomite limestone sandstone shale
		Ordovician	O 1	limestone sandy limestone sandstone
■	**Proterozoic**		P 6	conglomerate sandstone shale dolomite limestone
			P 5	igneous/sedimentary complex diabase gabbro diorite ultramafic basalt tuff/sandstone shale argillite iron formation
			P 4	diabase gabbro diorite ultramafic rocks granophyre
			P 3	slightly to strongly metamorphosed sedimentary rocks (gneissic) with gabbro and diorite igneous intrusives
			P 2	anorthosite (intrusive igneous)
			P 1	metamorphosed volcanic rocks with basic and ultrabasic igneous intrusions
▨	**Archean**		A 3	granitic intrusions granitic gneiss migmatite granulitic gneiss charnockite
			A 2	slightly to strongly metamorphosed sedimentary rocks (gneissic) with gabbro and diorite igneous intrusives
			A 1	metamorphosed volcanic rocks with basic and ultrabasic igneous intrusions

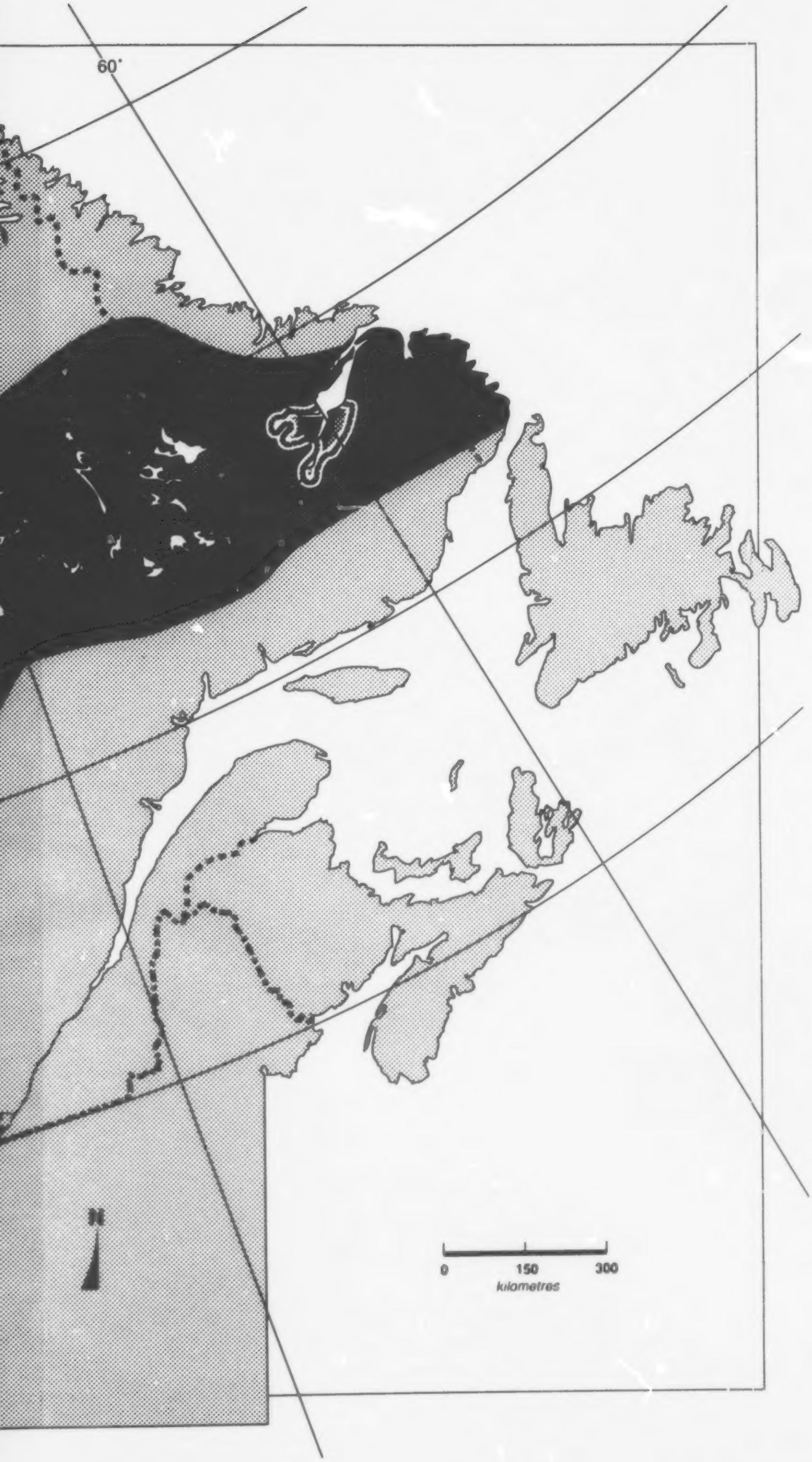
Sources
Geological Map of Canada, 1:5m (Energy, Mines & Resources, 1970)

Geological Highway Map of Northern Ontario, 1:600,000
(Ministry of Northern Development & Mines, 1979)

Principal Mineral Areas of Canada, 1:7,603,200
(Energy, Mines & Resources, 1988)

Projection: polar stereographic


Hudson Bay
James Bay
Ungava Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
60°
55°
50°
45°
N



map 2.5.4

NORTHERN WETLANDS STUDY AREA

Surficial Geology

▩	Glaciomarine	- primarily clayey silts and silty clays - includes gravelly coarse sand raised beach ridges surrounding Hudson and James Bays
▨	Glaciolacustrine	- primarily silts, silty clays and clays
▩	Ground moraine	- shallow to deep loamy to sandy tills over bedrock - includes gravelly and coarse sandy glaciofluvial deposits such as eskers, kames and glaciofluvial outwash plains
■	Till veneer over bedrock and exposed bedrock	
■	Primarily exposed bedrock	
ʃ	Maximum extent of postglacial marine inundation	

Source:
Glacial Map of Canada, 1:5m (Energy, Mines & Resources, 1970)
Soil Landscapes of Canada: Manitoba, 1:1m (Manitoba-Canada Soil Survey, 1986)
Surficial Geology of Northern Ontario, 1:12m
(Ministry of Mines & Northern Development, 1987)
Ecosystem Sensitivity to Acid Precipitation for Quebec, 1:2.5m (Gilbert et al., 1985)
Landscape Ecoregions of Quebec, 1:2.5m (Gilbert et al., 1985)
Ecological Land Classification of Labrador, 1:1m (Lopoukhine et al., 1978)

Projection: polar sterographic

The bedrock-controlled areas occur on the Canadian Shield and are characterized by rolling to hilly topography with lakes and wetlands occurring in pockets or depressions in the bedrock surface. Modification of this surface by thick glacial deposits as shown on Map 2.5.4 greatly increases the potential for wetland development.

Most of the Shield consists of exposed bedrock or a thin till veneer over bedrock. The next most widespread surficial class is mapped as ground moraine. This material consists of a combination of basal till and ablation till which are primarily derived from Shield rocks. Basal till (laid down at the base of the ice sheet) consists of a mixture of silt, sand and boulders. It tends to be very compact due to pressure from the overlying ice and consequently has low permeability. Hence, drainage is poor to imperfect and, when impeded by surface features such as drumlins, large wetland complexes are formed. This is particularly common on the large drumlinized till plains found in southern Labrador. Ablation till, in contrast, contains a looser mixture of materials which were deposited as the ice melted and receded. These sediments tend to be more oxidized and have a greater infiltration capacity.

Glaciolacustrine sediments are fine-grained clays and silts which were deposited over large areas of the Shield and the Manitoba Plain due to the existence of extensive glacial lakes. These lakes formed in front of the ice sheet as it retreated north. The sediments shown on the map are primarily derived from two large glacial lakes: glacial Lake Agassiz (Manitoba and northwestern Ontario) and glacial Lake Barlow-Ojibway (northeastern Ontario). These areas are imperfectly to poorly drained and, in association with flat surface expression, result in numerous wetlands and expansive wetland areas. Extensive wetlands surrounding Lake Winnipeg as well as in northern Manitoba and northeastern Ontario (clay belt) have formed on glaciolacustrine deposits.

The glaciomarine sediments of the Hudson Bay Lowland consist of carbonate-rich clays and silts. The occurrence of fine-grained sediments overlying an extensive low-relief coastal plain has resulted in the development of continuous wetland complexes in the Lowland. To the east and northeast of James Bay, marine sediments are not as continuous and the topography is controlled by the bedrock of the Shield. As a result, wetlands in this area are more restricted in extent.

2.5.5 REFERENCES

Bostock, H.S. 1970. Physiographic subdivisions of Canada. *In. Geology and Economic Minerals of Canada.* R.J.W. Douglas (editor), Dept. Energy, Mines and Resources, Queen's Printer, Ottawa: 10-30.

Braithwaite, M. 1970. The Western Plains. The Illustrated Natural History of Canada. Toronto.

Clark, T.H. and C.W. Stearn. 1968. Geological Evolution of North America. The Ronald Press Co. NY.

Douglas, R.J.W., H. Gabrielse, J.O. Wheeler, D.F. Stott and H.R. Belyea. 1970. Geology of western Canada. *In. Geology and Economic Minerals of Canada.* R.J.W. Douglas (editor), Dept. Energy, Mines and Resources, Queen's Printer, Ottawa: 366-488.

Energy, Mines and Resources. 1970. Geology and economic minerals of Canada. R.J.W. Douglas (scientific editor), Geological Survey of Canada, Economic Geology Report No. 1, Maps 1250 A (Geological Map of Canada), 1253 A (Glacial Map of Canada) and 1254 A (Physiographic Regions of Canada): scale 1:5,000,000.

Energy, Mines and Resources. 1974. *The National Atlas of Canada.* 4th Edition, Macmillan Co. of Canada, Toronto.

Energy, Mines and Resources. 1988. Principal Mineral Areas of Canada. Geological Survey of Canada, Ottawa, Ontario, Map 900A: scale 1:7,603,200.

Gilbert, G., R.G. Helie and J.M. Mondoux. 1985. Ecosystem sensitivity to acid precipitation for Québec. Part A: ecoregions and ecodistricts of Québec. Ecological Land Class. Series No. 20, Lands Direct., Environment Canada, Ottawa, Ontario: 87p. plus 1:2.5 million scale maps.

Lopoukhine, N., N.A. Prout and H.E. Hirvonen. 1978. Ecological Land Classification of Labrador. Lands Dir., Fisheries and Environment Canada, Ecological Land Classification Series No. 4. Halifax, N.S.: 85p plus fold-out map.

Manitoba-Canada Soil Survey. 1986. Soil landscapes of Canada: Manitoba. Land Resource Research Centre, Agriculture Canada, Ottawa, Ontario: scale 1:1,000,000.

Ministry of Mines and Northern Development. 1979. Geological Highway Map—Northern Ontario. Ontario Geological Survey, Toronto, Ontario: scale 1:600,000.

Ministry of Mines and Northern Development. 1987. Surficial Geology of Northern Ontario. Ontario Geological Survey, Map 2518: scale 1:1,200,000.

National Wetlands Working Group. 1986. Canada's Wetlands: maps of wetland regions and distribution in Canada. Canada Committee on Ecological Land Classification, Lands Dir., Environment Canada, Ottawa: 2 maps at 1:7.5 m scale plus fact sheet.

Onakawana Development Ltd. 1973. Onakawana Project; lignite mine and power plant development, engineering feasibility study and economic analyses. Ont. Min. Nat. Res. Rept. 5366-4-73: 2 vol.

Riley, J.L. 1982. Hudson Bay Lowland floristic inventory, wetlands catalogue and conservation strategy. *Naturaliste can.*, 109: 543-555.

Stockwell, C.H., J.C. McGlynn, R.F. Emslie, B.V. Sanford, A.W. Norris, J.A. Donaldson, W.F. Fahrig and K.L. Currie. 1970. Geology of the Canadian Shield. *In. Geology and Economic Minerals of Canada.* R.J.W. Douglas (editor), Dept. Energy, Mines and Resources, Queen's Printer, Ottawa: 44-150.

2.6 SOILS AND PERMAFROST

2.6.1 SOILS AND SOIL CLIMATES

Soils are defined as "...naturally occurring, unconsolidated, mineral or organic material at the earth's surface that is capable of supporting plant growth" (CSSC 1978). Soils are the product of the interaction between surficial materials and climate over time. Air temperature, precipitation, vegetation, slope, texture of the parent materials and time are the key soil forming factors which affect the extent and nature of soil.

2.6.1.1 SOIL TYPES, DISTRIBUTION AND DEVELOPMENT

The Canadian System of Soil Classification recognizes 9 major soil Orders into which all soils in Canada are classified. The classification system is hierarchical such that each order is subdivided into Soil Great Groups which are in turn subdivided into Subgroups. For a detailed description of the major chemical and physical characteristics of Canadian soils the reader is referred to the *Canadian System of Soil Classification* (CSSC 1978) and *Soils of Canada* (Clayton *et al.* 1977).

Eight of the nine Soil Orders are found within the Northern Wetlands Study area (Map 2.6.1). These include the Chernozemic, Luvisolic, Podzolic, Brunisolic, Regosolic, Gleysolic, Organic and Cryosolic Orders. The Solonetzic Order is not found in the study area. Map 2.6.1 identifies the dominant soil Great Groups (based on occupying 50 percent or more of the map unit).

All soils which develop in wetland areas are classified as Organic, Cryosolic or Gleysolic. If the depth of peat within the wetland exceeds 40 cm, the soils are classified as Organic. Soils of bogs, fens and poor swamps are predominantly classified in the Organic Order. This Order is subdivided into Fibrisol, Mesisol and Humisol Great Groups based on the degree of peat decomposition. Fibrisols are the least decomposed; Mesisols are moderately decomposed; and Humisols are the most decomposed. This gradient in humification relates to decreasing ratios of carbon to nitrogen as the organic material decomposes.

Peatland soils with permafrost are classified in the Organic Cryosol Great Group of the Cryosolic Order. These are defined as having in excess of 40 cm of peat and permafrost within 1 m of the surface.

Gleysolic soils are mineral soils (less than 40 cm of peat accumulation) which form under conditions of a high water table and/or prolonged saturation. These soils occur in imperfectly drained upland forests and mineral soil wetlands such as marshes and rich swamps.

Chernozemic Soils (A)

Chernozemic soils are well to imperfectly drained soils having surface horizons darkened by the accumulation of organic matter from the decomposition of grasses and forbs under dry to normal moisture conditions (Clayton *et al.* 1977, CSSC 1978). These soils are characteristic of the Prairies, forming under grassland or transitional grassland-forest conditions. Chernozems occur only in the extreme southwest of the map area, in the vicinity of Lake Manitoba.

These soils have good soil structure with dark coloured, humus-rich upper horizons with lower horizons enriched in bases (Clayton *et al.* 1977). They develop in areas of cool Boreal to cold Cryoboreal, Subhumid to Subarid continental soil climates typical of south-central Canada (Section 2.6.1.2).

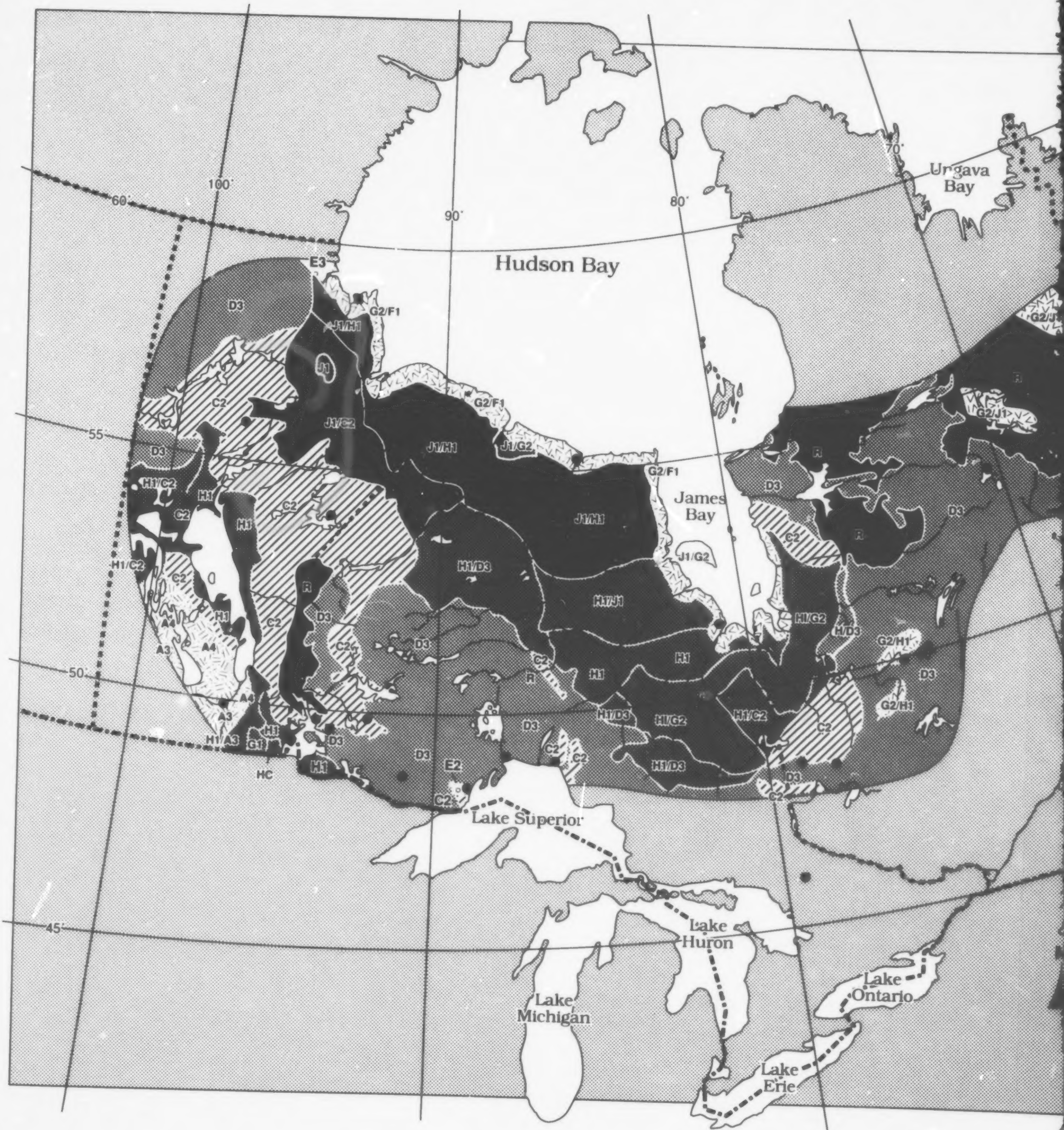
Two Great Groups, the Black Chernozemic and Dark Gray Chernozemic subgroups, are found within the map area. The Black Chernozemic soils are more typical of true Prairie grasslands with Subhumid moisture conditions. Dark Gray Chernozemic soils form under Sub-humid to Humid conditions in areas of grassland-forest transition.

Luvisolic Soils (C)

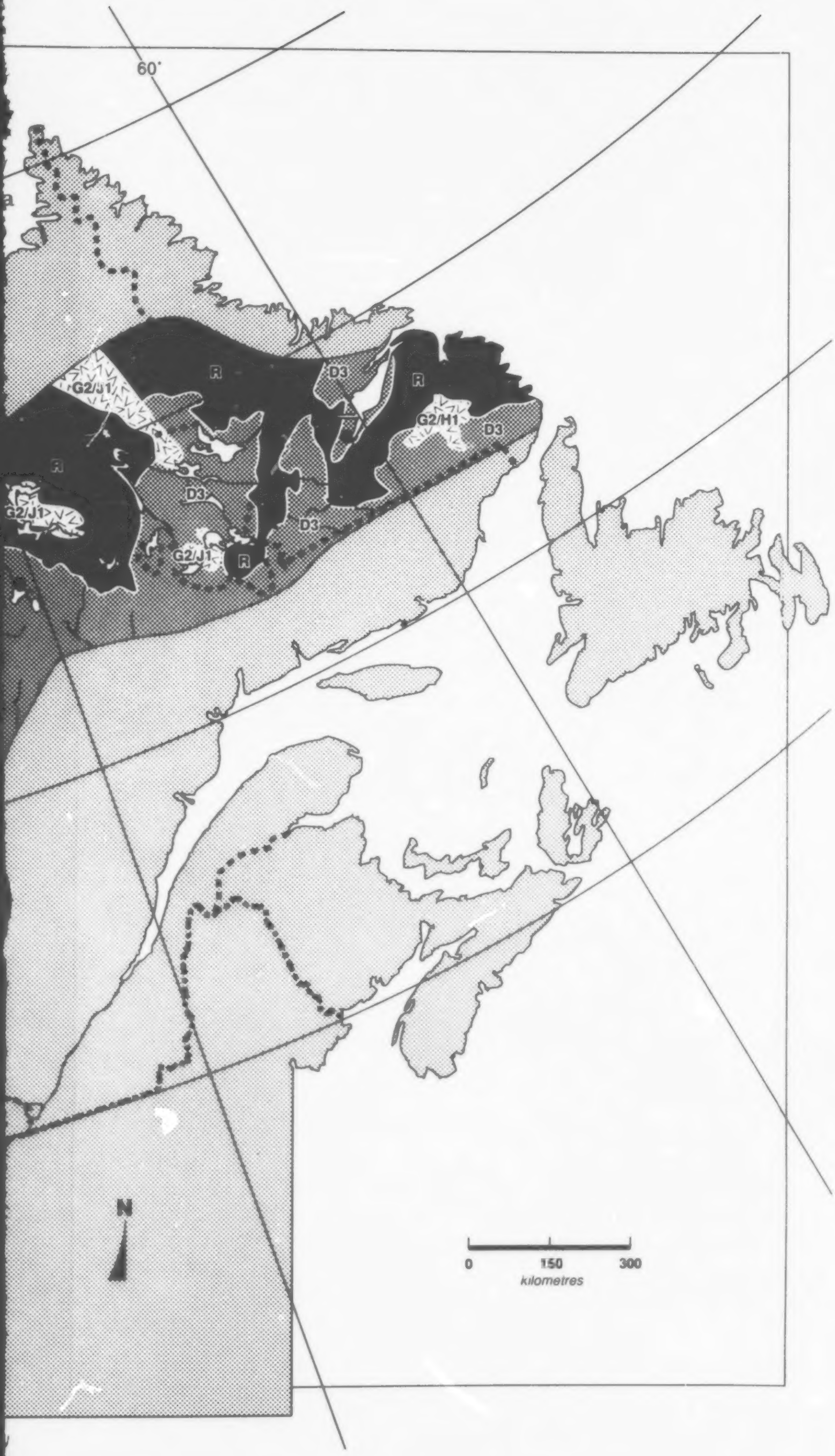
Luvisolic soils form in mild to cold climates under forest vegetation and are well to imperfectly drained (Clayton *et al.* 1977, CSSC 1978). They are characterized by the leaching of colloidal material from light-coloured upper soil horizons and accumulation in middle horizons. The most diagnostic feature of these soils is the enrichment of silicate clays in the middle horizon. The upper portions of these soils vary from neutral to moderately acid while parent materials are generally neutral to alkaline and may have accumulations of lime.

Luvisolic soils occur most frequently in western Québec and central to southeastern Manitoba. They are also found in northwestern and northeastern Ontario. Luvisols are most commonly formed on fine-grained glaciolacustrine surficial deposits. Generally, they occupy the better drained portions of these areas with wetter soils (Gleysolic and Organic) occurring on the poorly drained sites.

Luvisols of the study area are primarily Gray Luvisols. These soils form under Boreal forest vegetation (primarily coniferous and mixed coniferous-deciduous) and Boreal to Cryoboreal soil climates.



Hudson Bay
James Bay
Ungava Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°
E3
D3
G2/F1
J1/H1
J1
J1/C2
C2
D3
H1/C2
H1
C2
H1
J1/H1
J1/G2
G2/F1
J1/H1
H1/D3
H1/J1
J1/G2
H1/C2
C2
A4
A3
A4
H1
C2
R
D3
C2
D3
C2
R
H1
H1/D3
H1/G2
H1/C2
H1/D3
A4
A3
H1
H1 A3
G1
D3
HC
H1
D3
E2
C2
D3
C2
C2
D3
C2
H1/G2
H/D3
G2/H1
D3
G2/H1
C2
R
D3
C2
R
D3
R
G2/J1
G2/J1



map 2.6.1

NORTHERN WETLANDS STUDY AREA

Soils

	Dominant Soil Order	Dominant Great Group
▢	**Chernozemic**	A3 Black Chernozemic A4 Dark Gray Chernozemic
▨	**Luvisolic**	C2 Gray Luvisol
▩	**Podzolic**	D3 Humo-Ferric Podzol
▢	**Brunisolic**	E2 Eutric Brunisol E3 Dystric Brunisol
*not present in a majority situation	**Regosolic**	F1 Orthic Regosol
▢	**Gleysolic**	G1 Humic Gleysol G2 Orthic Gleysol
■	**Organic**	H1 Fibrisols and Mesisols
■	**Cryosolic**	J1 Organic Cryosols
■	**Rockland**	R

* where two classes identified, first occupies >50% of area

Source
Soil Map of Canada/LRRI 1:5m (Agriculture Canada, 1972)
Distribution of Wetlands 1:7.5m (National Wetlands Working Group, 1986)

Projection: polar stereographic

Podzolic Soils (D)

Podzolic soils are well to imperfectly drained mineral soils which have formed under acid leaching conditions (Clayton *et al.* 1977, CSSC 1978). Base content is low due to leaching by organic acids and colloids which move down through the profile and accumulate in middle horizons. The organic material is the product of heath and conifer forest vegetation. Podzolic middle horizons are characterized by accumulations of soluble organic material and/or oxides of iron and aluminum. Soil climate conditions are typically cold to mild and Humid to Perhumid (Section 2.6.1.2).

Podzols representing the Humo-Ferric Podzol Great Group occur throughout the Northern Wetlands Study area. They form primarily on acidic boulder tills in areas of ground moraine and ablation till. Rocks of the Canadian Shield provide the major source of the surficial material and Podzolic soils are most prevalent on the Shield. Localized areas having Podzolic soils, particularly Humic Podzols and Ferro-Humic Podzols, are found on raised beach deposits of the Hudson Bay Lowland in Ontario and western Québec. These Podzols have formed on calcareous materials within 1,000 years since the formation of the beach ridges (Protz 1982a, Protz *et al.* 1984 and 1988).

Brunisolic Soils (E)

Brunisols develop on well to imperfectly drained mineral soils. They are characterized by brownish middle horizons which are not sufficiently altered to meet physical or chemical requirements of other soils such as the Podzols or Luvisols. Hence, their soil chemistry largely reflects conditions of the original surficial material and may be acidic (Dystric Brunisols) or basic (Eutric Brunisols) (Clayton *et al.* 1977, CSSC 1978). Generally, Brunisols tend to be slightly more acid in their upper horizons due to minor leaching.

Areas mapped as dominantly Brunisolic soils within the Northern Wetlands Study area are limited in extent (Map 2.6.1). These map units are found only near Thunder Bay, Ontario and north of Churchill, Manitoba. Brunisols form under a wide range of climatic and vegetation conditions in various parent materials. Thus, they are common throughout the study area in association with other soil types.

Soil temperature and moisture conditions range from Mesic to Arctic and from Perhumid to Semiarid, respectively (Section 2.6.1.2). Generally, Brunisols become more widespread in the north having their greatest expression outside the study area in the south-central Northwest Territories and in the Yukon Territory.

Regosolic Soils (F)

Regosolic soils are those whose development is too weak to meet the requirements of any other order (Clayton *et al.* 1977, CSSC 1978). Regosols occur on unconsolidated parent materials which have undergone minimal weathering and, hence, may be acidic or basic depending on the source of the surficial material.

Within the Northern Wetlands Study area Regosols are mapped only as a subdominant class in the immediate coastal area of the Hudson Bay Lowland. They occur on calcareous beach materials which, although undergoing podzolization, are too young (due to glacial rebound) to display soil forming characteristics (Protz *et al.* 1984 and 1988).

Regosolic soils in Canada are most widespread in the far north where youthfulness (most recently deglaciated) and extreme climatic conditions limit soil development.

Gleysolic Soils (G)

Gleysols are poorly drained mineral soils in which the water table is at or near the surface for significant periods of the year (Clayton *et al.* 1977, CSSC 1978). They develop under hydrophytic vegetation including sedge-grass, thicket/shrub, forest or tundra communities. Gleysols occur in Subaquic to Peraquic moisture regimes under all temperature classes as defined by soil climates (Section 2.6.1.2).

Oxygen reducing conditions occurring during saturation result in the development of characteristic 'gley' colours or mottling within Gleysolic soils. Gleying is a readily recognizable feature in the form of gray, olive, blue-gray or greenish colours in the main body of the soil profile and/or the presence of red and reddish-yellow mottles.

The high water table associated with Gleysolic soils limits downward migration of bases or oxides of aluminum and iron. Hence, the chemistry of these soils reflects the original parent material which may be acidic or basic. Gleysols are commonly fine-textured with restricted internal drainage. They are most widespread on the silts and clays of former glacial lake and marine deposits.

Gleysolic soils occur throughout the Northern Wetlands Study area, usually in combination with Organic soils (Map 2.6.1). They form the dominant soil along the low-lying coastal portion of Hudson and James Bays (Protz 1982b), in central Québec and southeast Labrador. They occur as a subdominant class in areas dominated by Organic soils such as northeastern Ontario and west-central Québec.

Organic Soils (H)

Organic soils developed as a result of the net surface accumulation of organic material. They are primarily formed from hydrophytic sedges and mosses characteristic of permanently saturated soils (Clayton *et al.* 1977, CSSC 1978). The water table lies above the mineral substrate for most or all of the year, usually within a few centimetres of the surface of the organic deposit.

Within the Northern Wetlands Study area, Organic soils dominate and occur in combination with Gleysolic or Cryosolic soils over large areas of northern Ontario, central and northern Manitoba and western Québec (Map 2.6.1). The Hudson Bay Lowland and the area surrounding Lake Winnipeg are characterized by large expanses of continuous Organic soil types. These soils are more restricted in extent on the Canadian Shield where they are limited to bedrock depressions and areas of compact morainal material.

Cryosolic Soils (J)

Cryosols occur primarily in the northern third of Canada where permafrost occurs within 2 m of the surface (CSSC 1978). They develop in both mineral and organic deposits. Soil climates of these soils are primarily Arctic to Sub-arctic and include all moisture regimes (Section 2.6.1.2). They are classified into three Great Groups. Organic Cryosols have a peat thickness in excess of 40 cm. Mineral soils are classified as either Static Cryosols or Turbic Cryosols based on the degree of disruption of the soil by frost processes (cryoturbation).

Within the Northern Wetlands Study area, Organic Cryosols tend to be widespread in the northern portion of the Hudson Bay Lowland (Map 2.6.1) where they form the major soil type in permafrost organic landforms such as palsas and peat plateaus. As such, they are most common in the northwestern Lowland, gradually becoming less abundant toward the south and east.

2.6.1.2 SOIL CLIMATES

Soil climates (Map 2.6.2) have been developed on the basis of the interaction of climatic conditions above ground, at the ground surface and within the upper 1 m of the soil/root environment (Clayton *et al.* 1977). Soil temperature conditions at the surface and below ground are affected by moisture conditions and thus soil climates include a soil moisture classification.

Temperature regimes are developed using ranges of measured soil temperatures to define the growing season, the dormant season and the frozen period. Each temperature class is based on a characterization of these periods with regard to length, mean soil temperature (at 50 cm depth) and accumulated degree-days (see Table 2.6.1).

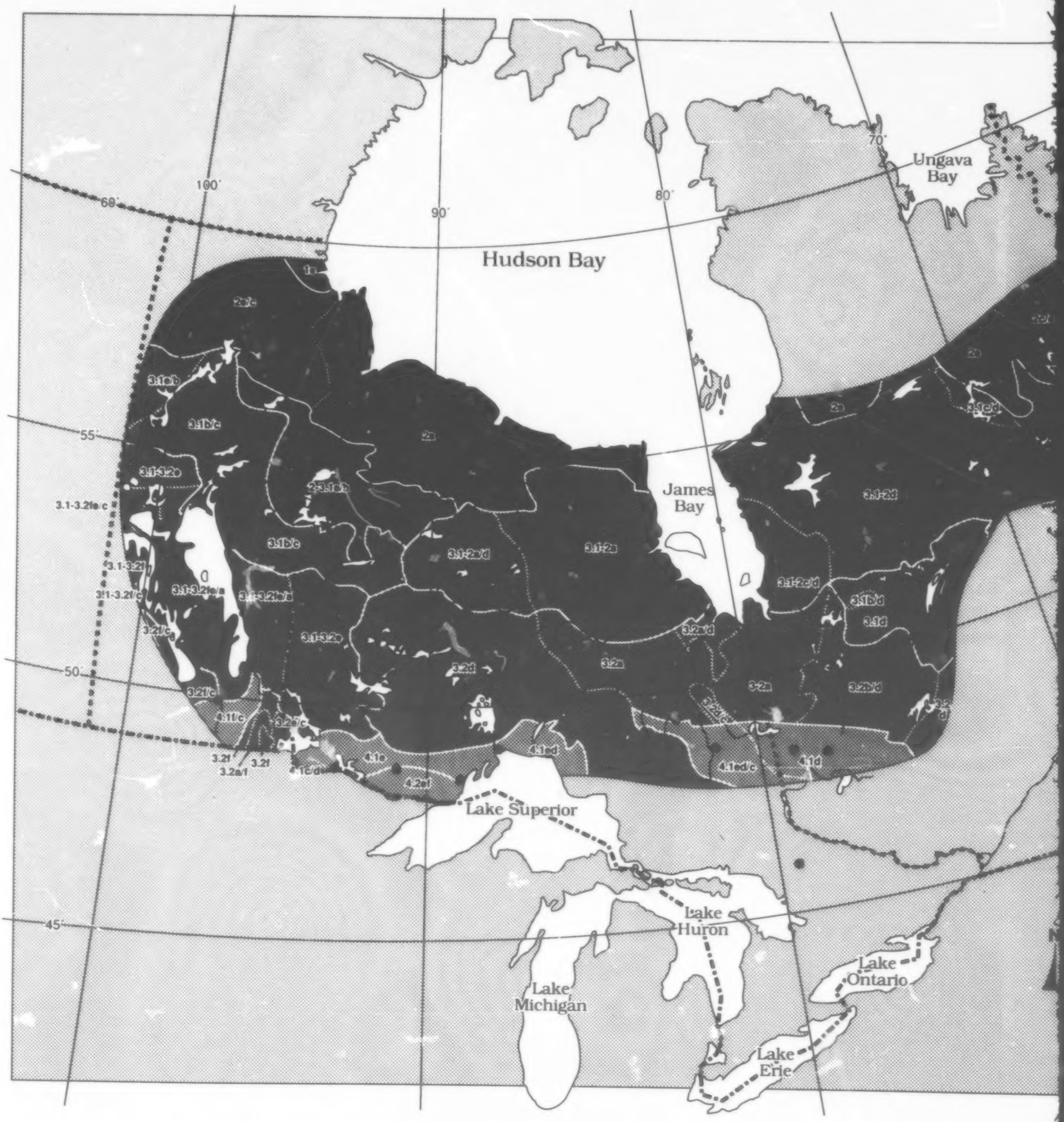
Moisture regimes are based on the period of saturation (Peraquic, Aquic and Subaquic-see Map 2.6.2 Legend) and the intensity and degree of water deficit (Perhumid, Humid and Subhumid). Soil moisture conditions play a prominent role in affecting microclimatic conditions and determining the plant communities present. The three aquic subclasses are based on a subjective estimation of the length of the saturated period of associated soils and are important with regard to wetlands. These subclasses were introduced to characterize areas dominated by imperfectly to very poorly drained soils (Clayton *et al.* 1977) such as Gleysols and Organic soils (Section 2.6.1.1) which include all wetland areas.

TABLE 2.6.1

Characteristics of the four soil temperature classes occurring in the Northern Wetlands Study area (see Map 2.6.2).

TEMPERATURE CLASS	MEAN ANNUAL SOIL TEMPERATURE (°C)	MEAN SUMMER SOIL TEMPERATURE (°C)	GROWING SEASON >5°C (days)	GROWING SEASON DEGREE-DAYS >5°C	THERMAL PERIOD >15°C (days)	THERMAL PERIOD DEGREE-DAYS >15°C
ARCTIC	<-7	<5	<15	—	no thermal period	—
SUB-ARCTIC	-7 to 2	5 to 8	<120	<555	no thermal period	—
CRYOBOREAL	2 to 8	8 to 15			no significant days	<33
Cold			120 to 180	555 to 1110		
Moderately cold			<220	1110 to 1250		
BOREAL	5 to 8	15 to 18				33 to 222
Cool			>170	1250 to 1388	<60	
Moderately cool			>220	1388 to 1720	<120	

SOURCE: Clayton *et al.* 1977



Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°
1e
2e/c
3.1e/b
3.1b/c
3.1-3.2e
3.1-3.2le/c
2-3.1e/b
3.1b/c
3.1-3.2l
3.1-3.2le/a
3.1-3.2le/a
3.1-3.2l/c
3.2l/c
3.1-3.2e
3.2l/c
4.1l/c
3.2e/c
3.2l
3.2l
3.2a/l
4.1c/d
4.1e
4.2el
2a
3.1-2a/d
3.1-2a
3.2d
4.1ed
3.2a/d
3.2a
3.2d/c
3-2a
4.1ed/c
4.1d
3.1-2d
3.1-2c/d
3.1b/d
3.1d
3.2b/d
2a
2e
3.1c/d

Soil climates, as delineated by Clayton *et al.* (1977), include seven major temperature classes modified by ten moisture subclasses. The temperature classes are identified as: Arctic, Sub-arctic, Cryoboreal, Boreal, Mesic, Thermic and Hyperthermic. The first four occur within the map area. Moisture subclasses include three aquic regimes (Peraquic, Aquic and Subaquic) and seven moist/submoist regimes (Perhumid, Humid, Subhumid, Semiarid, Subarid, Arid and Xeric). Six moisture subclasses are represented in the map area. These include all three aquic regimes and the first three moist/submoist regimes as listed above.

The characteristics of the four temperature classes which occur in the study area are identified in Table 2.6.1 and their distribution is shown in Map 2.6.2. Soil climates range from Boreal in the south to Arctic in the northeast and northwest of the Northern Wetlands Study area. Arctic conditions correspond to areas of continuous permafrost and are restricted to small areas in Manitoba and Labrador. Cooler July mean daily air temperature (Map 2.3.2A), due to the maritime influence along the Atlantic coast in Labrador, is not observed on Map 2.6.2.

Soils throughout most of the Northern Wetlands Study area have a distinct moisture surplus (i.e., Peraquic through Perhumid subclasses, Map 2.6.2). Slight moisture deficits (i.e., Humid subclass) are restricted to the coarse textured tills of northwestern Ontario and portions of Manitoba. Significant moisture deficits (i.e., Subhumid subclass) occur only in the extreme southwestern portion of the study area in Manitoba. This also corresponds to the area of highest mean daily July air temperatures, annual global solar radiation and annual total growing degree-days as well as to the lowest mean annual total precipitation.

In comparing the soils map (Map 2.6.1) with soil climates (Map 2.6.2), it is apparent that the areas dominated by organic, organic cryosolic and gleysolic soils correspond to areas classified as Sub-arctic and Cryoboreal in combination with Peraquic, Aquic or Subaquic conditions. These areas also have the highest concentration of wetlands. Temperature (air and soil) along with soil moisture thus appear to play a dominant role in the formation and development of wetlands.

2.6.2 PERMAFROST

Permafrost is defined by Brown and Kupsch (1974) as "...the thermal condition in soil or rock of having temperatures below 0°C persist over at least two consecutive winters and the intervening summer". It is a thermal condition and ice may or may not be present. The ice may be present as coatings on particles, layers, wedges, crack fillings or irregular masses (Brown 1978).

At the surface is a layer of soil or rock, known as the active layer which thaws in summer and freezes each winter (Brown 1978). The depth of the active layer is a function of the insulation properties of the soil material and the degree of heating at the surface. In wetlands, permafrost forms in peat materials through which horizontal water movement is generally absent or restricted such as in bogs and some fens. Peat provides greater insulation than mineral soils resulting in thinner active layers and longer duration of seasonal ice into the summer period in peatlands. Permafrost occurrence is generally restricted to peatlands in more southerly areas.

The permafrost map (Map 2.6.3) is taken from the *Hydrological Atlas of Canada* (Fisheries and Environment Canada 1978). This map was prepared by R.J.E. Brown and represents an update of the original *Permafrost in Canada* map prepared by Brown (1967). Brown (1967, 1978) utilized field observations of permafrost occurrence and measurements or estimates of mean annual ground temperature to identify permafrost zones. Mean annual ground temperature was measured below the zone of seasonal variation at selected sites and extrapolated using mean annual air temperature. Air temperatures are based on a 30 year average (1941-1970). A broad relationship between mean annual air and ground temperatures was established. Mean annual ground temperature is on average 3.3°C warmer than the mean annual air temperature (Brown, 1978). Two major permafrost zones are identified: the continuous and discontinuous permafrost zones (Map 2.6.3). The latter is subdivided into areas of widespread and scattered permafrost.

The division between continuous and discontinuous permafrost is based on the −5°C isotherm of mean annual ground temperature which corresponds approximately to a mean annual air temperature of −8.3°C (Brown 1967). In the Northern Wetlands Study area, this occurs only in the extreme northwest. Brown (1978) shows the zone of continuous permafrost following the south shore of Hudson Bay as far as the shore of James Bay. This represents its most southerly extent in Canada and is the only place, other than in mountainous regions, where the southern extent of continuous permafrost crosses south of the −5°C isotherm of mean annual air temperature. More recent data indicate that the continuous zone may not reach this far south (French and Gilbert 1982). The map of soil climates (Map 2.6.2) does not show continuous permafrost ('Arctic Regime') this far south.

In the continuous zone, permafrost varies in thickness from about 100 m along the southern margin to over 1000 m in the far north. The discontinuous zone has permafrost up to 100 m in thickness but it is not continuous in aerial extent or in some cases, in the vertical dimension as well (i.e., unfrozen layers alternating with frozen layers). In this zone, the depth to permafrost is also highly variable ranging from 0.7 m to several tens of meters (Brown 1967). The thickest permafrost measured within the map area is in the discontinuous zone near Schefferville where it is 125 m thick.

The southernmost limit of discontinuous permafrost coincides approximately with the -1.0°C mean annual air temperature isotherm. This limit, in general, is poorly defined and may fluctuate depending on global temperature cycles. Temperature measurements taken in a borehole in northern Ontario, for example, suggests that substantial warming has occurred in the last 50 to 100 years (A. Judge, pers. com.). In addition, some of the sites studied by Brown in northern Manitoba have recently been revisited and were found to have no ground ice (A. Judge, pers. com.).

Permafrost, either continuous or discontinuous, occurs over more than half of the Northern Wetlands Study area; scattered permafrost is the predominant permafrost condition. Continuous and widespread permafrost is confined to the northernmost portion of the map area in Manitoba, Ontario and Québec.

Wetlands, particularly peatlands, are profoundly affected by permafrost and, in turn, affect permafrost development. Gore (1983) notes that within the area of discontinuous and continuous permafrost, wetland shape is "...much more related to the dominant effects of frost and ice than to the effects of liquid water drainage so predominant in the North Temperate and Boreal Zones". Wetland shape in this instance refers to the formation of distinctive features such as raised mounds (palsas and peat plateau), raised ridges (strings) or linear cracks (ice wedge polygons) which form by expansion of the peat deposit as water freezes.

These features, and the presence of permafrost near the surface of the peat deposit, restrict vertical drainage (Section 2.7.5). Surface moisture drains laterally, particularly in mounded peatlands, resulting in decreased soil moisture, increased thermal insulation and decreased evapotranspiration (Brown 1968, Moore and Bellamy 1974, Roulet and Woo 1986 and Zoltai *et al.* 1988). Thus, an important consequence of the active development of permafrost in previously non-frozen peatlands is the establishment of drier surface conditions which promotes aerobic conditions and lower methane production.

The presence of peat affects the extent and thickness of permafrost occurrences (Brown 1968). Brown (1968) notes that permafrost occurs only in peatlands within the southern part of the discontinuous permafrost zone. This is related to changes in the thermal conductivity of peat through the year as affected by moisture content (Zoltai and Tarnocai 1969). The insulating properties of peats, such as sphagnum moss peats with relatively low moisture content, results in delayed thawing of seasonal ice in the southernmost portion of the discontinuous zone (Cowell *et al.* 1978). Cowell *et al.* (1978) note that these sites would likely become centres of permafrost formation under conditions of climatic cooling.

2.6.3 REFERENCES

Agriculture Canada. 1972. Soils of Canada. Soil Research Institute, Agriculture Canada, Ottawa, Ontario, Map: scale 1:5 million. (distributed with Clayton *et al.* 1977).

Agriculture Canada. 1975. Soil Climates of Canada. Soil Research Institute, Agriculture Canada, Ottawa, Ontario, Map: scale 1:10 million. (distributed with Clayton *et al.* 1977).

Brown, R.J.E. 1967. Permafrost In Canada. Geol. Surv. Can. Map 1246A and Nat. Res. Council of Canada, Pub. No. NRC 9769: scale 1:7,603,200.

Brown, R.J.E. 1968. Occurrence of permafrost in Canadian peatlands. Proc. 3rd Internat. Peat Congress, Québec, Canada: 174-181.

Brown, R.J.E. 1978. Permafrost. *In. Hydrological Atlas of Canada.* (text and map) Fisheries and Environment Canada, Supply and Services Canada, Ottawa, Ontario.

Brown, R.J.E. and W.O. Kupsch. 1974. Permafrost Terminology. Tech. Memo. No. 111, Assoc. Com. Geotech. Res., Nat. Res. Council of Canada: 62p.

Canada Soil Survey Committee (CSSC). 1978. The Canadian System of Soil Classification. Research Branch, Agriculture Canada, Pub. 1646: 164p.

Clark, T.H. and C.W. Stearn. 1968. *Geological Evolution of North America.* Ronald Press Co., N.Y.: 570p.

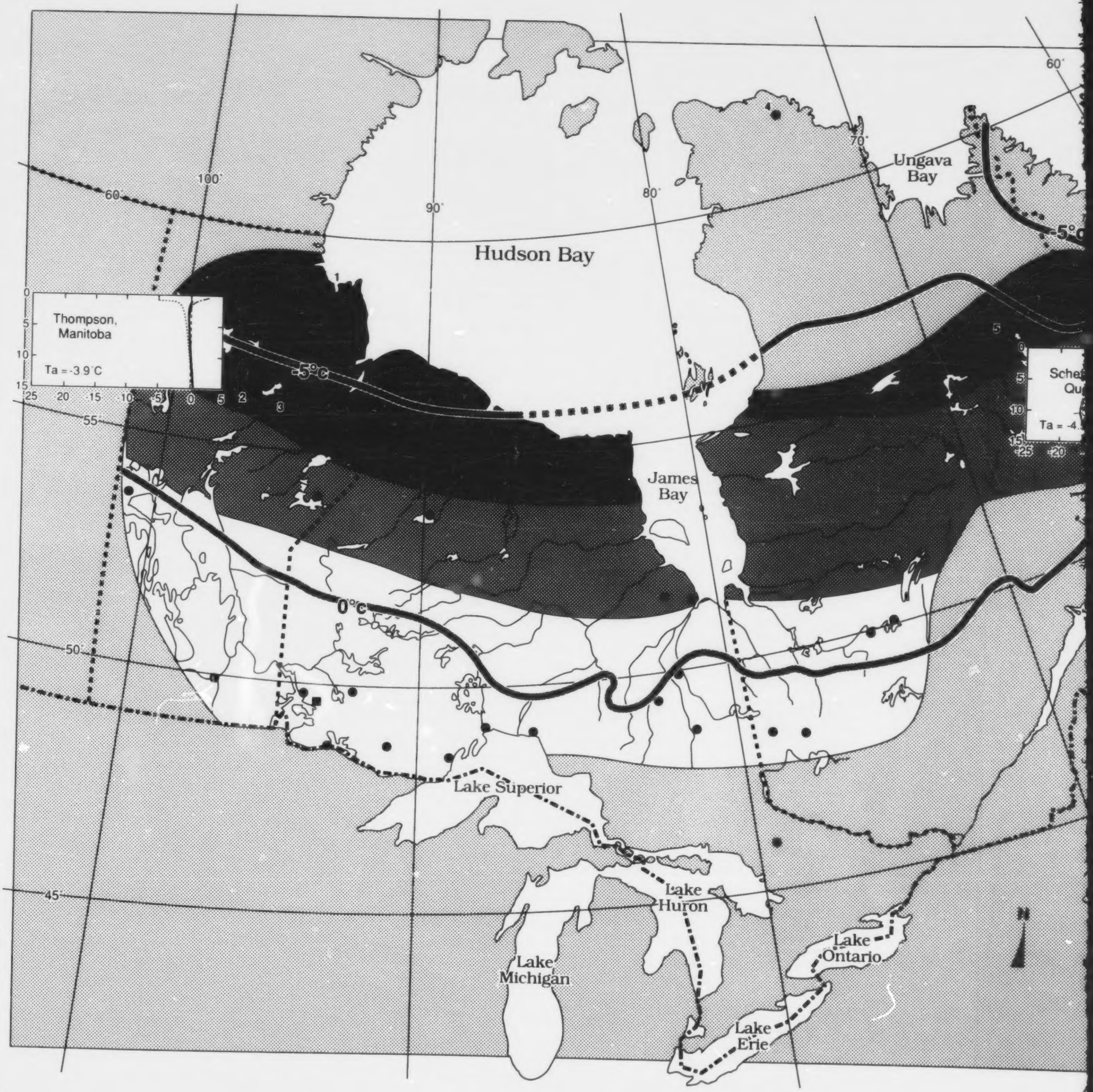
Clayton, J.S., W.A. Ehrlich, D.B. Cann, J.H. Day and I.B. Marshall. 1977. Soils of Canada. The Canada Soil Committee and The Soil Research Institute, Agriculture Canada, Ottawa, Ontario. 2 vol. with accompanying maps.

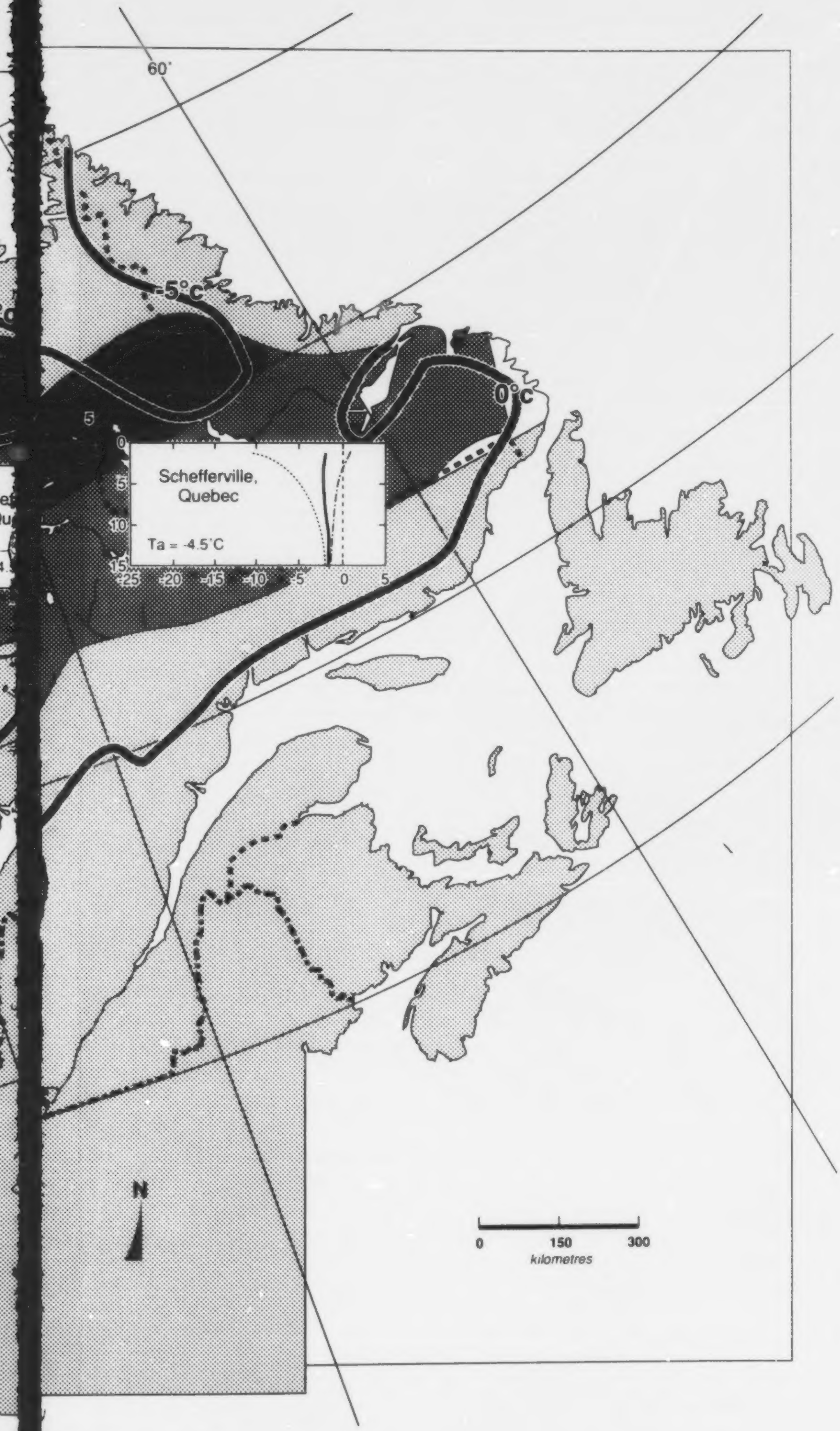
Cowell, D.W., J.K. Jeglum and J.C. Merriman. 1978. Preservation of seasonal frost in peatlands, Kinoje Lakes, southern Hudson Bay Lowland. Proc. 3rd Int. Conf. Permafrost, Edmonton, Alta: 453-459.

Fisheries and Environment Canada. 1978. *Hydrological Atlas of Canada.* Supply and Services Canada, Ottawa.

French, H.M. and R. Gilbert. 1982. Periglacial phenomena near Churchill, Manitoba. *Le Nat. Can.*, 109(3): 433-444.

Gore, A.J.P. 1983. Introduction. *In. Ecosystems of the world. Volume 4A. Mires: swamp, bog, fen and moor.* A.J.P. Gore, (editor). Elsevier Scientific Publishing Company, Amsterdam, The Netherlands: 1-34.


Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
60°
70°
80°
90°
100°
60°
55°
50°
45°
-5°C
-5°C
0°C
Thompson, Manitoba
Ta = -3.9°C
0
5
10
15
-25
-20
-15
-10
-5
0
5
2
3
1
5
Sche
Qu
Ta = -4.
0
5
10
15
-25
-20
N



map 2.6.3

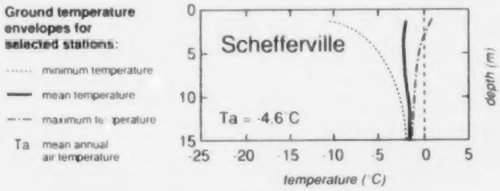
NORTHERN WETLANDS STUDY AREA

Permafrost

■	continuous permafrost zone
■	discontinuous permafrost zone - widespread
▨	discontinuous permafrost zone - scattered
▬	mean annual air temperature (°C)

	location	*mean annual air temp (°C)*	*ground temp (°C) at depth (m)*	*thickness of permafrost (m)*
1	Churchill, Man	-7.2	-2.5 to -1.7 (7-16)	60
2	Thompson, Man	-3.9	-0.5 to 0 (7)	0-15
3	Kelsey, Man	-3.6	-0.8 to -0.28 (9)	25
4	Asbestos Hill, Que	-8.3	-7.2 to -6.7 (15-60)	440
5	Schefferville, Que	-4.5	-1.1 to -0.28 (7-58)	125

Ground temperature envelopes for selected stations:



Source:
Permafrost in Canada, 1:7,603,200 (Brown, 1967)
Permafrost, 1:20m (Fisheries and Environment Canada, 1978)

Projection: polar stereographic

Manitoba-Canada Soil Survey. 1986. Soil landscapes of Canada: Manitoba. Land Resource Research Centre, Agriculture Canada, Ottawa, Ontario: scale 1:1,000,000.

Moore, P.D. and D.J. Bellamy. 1974. *Peatlands*. Springer-Verlag Inc. New York, N.Y.:221p.

National Wetlands Working Group. 1986. Canada's Wetlands: maps of wetland regions and distribution in Canada. Canada Committee on Ecological Land Classification, Lands Dir., Environment Canada, Ottawa: 2 maps at 1:7.5 m scale plus fact sheet.

Protz, R. 1982a. Development of podzolic soils in the Hudson and James Bay Lowlands, Ontario. *Naturaliste Can.*, 109: 501-510.

Protz, R. 1982b. Development of gleysolic soils in the Hudson and James Bay Coastal Zone, Ontario. *Naturaliste Can.*, 109: 491-500.

Protz, R., G.J. Ross, I.P. Martini and J. Terasmae. 1984. Rate of podzolic soil formation near Hudson Bay, Ontario. *Can. J. Soil Sci.*, 64: 31-49.

Protz, R., G.J. Ross, M.J. Shipitalo and J. Terasmae. 1988. Podzolic soil development in the southern James Bay Lowlands, Ontario. *Can. J. Soil Sci.*, 68: 287-305.

Riley, J.L. 1982. Hudson Bay Lowland floristic inventory, wetlands catalogue and conservation strategy. *Naturaliste can.*, 109: 543-555.

Roulet, N.T. and M.K. Woo. 1986. Hydrology of a wetland in the continuous permafrost region. *J. Hydrol.*, 89: 73-91.

Zoltai, S.C. 1988. Wetland environments and classification. Chapter 1. *In. Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 3-26.

Zoltai, S.C. and C. Tarnocai. 1969. Permafrost in peat landforms in northern Manitoba. Proc. 13th Annual Manitoba Soil Sci. Meeting: 16p.

Zoltai, S.C., C. Tarnocai, G.F. Mills and H. Veldhuis. 1988. Wetlands of Sub-arctic Canada. Chapter 3. *In. Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 57-96.

2.7 HYDROLOGY

Gray (1970) describes hydrology as the science of water, its properties, phenomena and distribution. It is defined in Chow (1964) as:

> "...the science that treats of the waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things."

The global supply of water circulates between the atmosphere and the Earth. Most components of the hydrological cycle are important to wetlands. Rain and snow nourish the soil and fill the lakes and streams while evaporation and transpiration return moisture to the atmosphere. Where precipitation is not offset by evaporation, water runs off, infiltrates the soil, recharges groundwater or is stored on the surface in basins or as ice. The cycle is extended or interrupted constantly as weather and storage change. When water passes through solid, liquid and gaseous stages there is considerable heat extraction from and release to the atmosphere.

As wetlands are intermediate between open water and terrestrial (upland) ecosystems, changes to the input or removal of water supplies can be critical. Water reduces aerobic decomposition processes and, hence, plant material accumulates to form peatlands. Peat accumulates more slowly or not at all if there is insufficient moisture to establish anaerobic conditions or if the water flows through the system too quickly. The establishment of anaerobic conditions enhances the production of CH_4. Wetland hydrological processes are discussed further in Section 2.7.5.

2.7.1 DRAINAGE BASINS

The total area drained by a river and all its tributaries is referred to as the drainage basin. Drainage basins of the Northern Wetlands Study area are shown in Map 2.7.1. Each basin is annotated according to its furthest downstream receiving waters: Hudson Bay (HB), Ungava Bay (U), the Great Lakes-St. Lawrence River (SL) and the Atlantic Ocean (A).

All or portions of 65 river basins (or sub-basins) occur within the Northern Wetlands Study area. Basins are identified that have an average annual streamflow of at least 280 m^3/s at their outlet or confluence with the larger basin. The names of each basin and sub-basin are listed in Table 2.7.1 along with the corresponding basin area. Eight of the sub-basins form portions of watersheds which have some or most of their flow diverted to adjacent watersheds for power generation purposes. Diversions are identified on the map. Table 2.7.2 provides specific information, including upstream basin area, for each of the eight diversions.

2.7.2 ANNUAL RUNOFF

Rainfall either infiltrates the soil to become soil moisture and groundwater or accumulates and flows from an area as surface runoff (Gray 1970). The amount of runoff is dependent on the intensity of precipitation,

TABLE 2.7.1

Major river basins and drainage areas of the Northern Wetlands Study area.

MAP ANNOTATION	BASIN	SUB-BASIN	AREA (km^2)
1. ***Hudson Bay Drainage***			4,041,000
HB-1	Hudson Bay	(not specified)	—
HB-2	Seal		50,000
	Churchill		281,274
HB-3A		Lower Churchill	
HB-3B		Diverted to HB-4A	
	Nelson		—
HB-4A		Lower Nelson	90,650
HB-4B		Saskatchewan	335,900
HB-4C		Lake Winnipeg	313,100
HB-4D		Assiniboine	182,000
HB-4E		Red	287,500
HB-4F		Winnipeg	29,600
HB-4G		Rainy	24,600
HB-4H		English	52,300
HB-5A	Hayes		36,600
HB-5B		Gods	71,400
HB-6	Severn		102,800
HB-7	Winisk		67,300
HB-8	Attawapiskat		50,500
HB-9A	Albany		84,400
HB-9B		Diverted to HB-4H	
HB-9C		Diverted to SL-1	
HB-9D		Kenogami	50,800
HB-9E		Diverted to SL-2	
HB-10A	Moose		18,500
HB-10B		Missinaibi	23,500
HB-10C		Mattagami	37,000
HB-10D		Abitibi	29,500
HB-11	Harricana		29,300
HB-12	Nottaway		65,800
HB-13	Broadback		20,800
HB-14	Rupert		43,300
HB-15A	Eastmain		46,400
HB-15B		Diverted to HB-16	
HB-16	La Grande		97,600
HB-17A	Baleine		42,700
HB-17B		Diverted to HB-16	
2. ***Ungava Bay Drainage***			(included with HB)
U-1A	Koksoak		37,600
U-1B		Canniapiscau	89,600
U-1C		Diverted to HB-16	
U-2	Nachicapau		6,200
U-3	Baleine		31,900
U-4A	George		41,700
U-4B		Diverted to A-3A	

TABLE 2.7.1 (cont'd)

MAP ANNOTATION	BASIN	SUB-BASIN	AREA (km^2)
3. *Saint Lawrence Drainage*			1,344,200
SL-1	Lake Nipigon		25,400
SL-2	Lake Superior	(not specified)	87,300
SL-3A	Ottawa		122,600
SL-3B		Gatineau	23,700
SL-4	St. Maurice		43,300
SL-5	Chamouchouane		15,700
SL-6	Mistassini		21,900
SL-7	Peribonca		26,200
SL-8	Outardes		19,000
SL-9A	Manicouagan		45,800
SL-9B		Ste. Marguerite	
SL-10A	Moisie		19,200
SL-10B		Lac Magpie	
4. *Atlantic Drainage*			699,700
A-1	Atlantic Ocean	(not specified)	—
A-2B	Naskaupi		18,100
A-2B		Diverted to A-3A	
A-3A	Churchill		41,800
A-3B		Ashuanipi	17,000
A-3C		Atikonak	21,000
A-4	Romaine		14,300
A-5	Natashquan		16,100
A-6	Little Mecatina		19,600
A-7	St. Augustin		9,900

SOURCE: Energy, Mines and Resources 1985

NOTE: 1. Basin area includes portions within the Northern Wetlands Study area as well as upstream (including areas in U.S.).
2. Basin area is for the specified map unit plus sub-basin or diversion units unless identified separately.

TABLE 2.7.2

Drainage diversions within the Northern Wetlands Study area.

DIVERSION	RECEIVING BASIN	MEAN ANN. DIVERSION FLOW (m^3/s)	% OF FLOW DIVERTED	BASIN AREA (km^2)
1. South Indian Lake (HB-3B)	Nelson (HB-4A)	760	70	249,239
2. L. St. Joseph (HB-9B)	English (HB-4H)	87	90	12,328
3. Ogoki (HB-9C)	Lake Nipigon (SL-1)	121	85	13,970
4. Long Lake (HB-9E)	Lake Superior (SL-2)	39	80	4,377
5. Opinaca (HB-15B)	La Grande (HB-16)	850	92	40,274
6. Baleine (HB-17B)	La Grande (HB-16)	29	5	1,710
7. Caniapiscau (U-1C)	La Grande (HB-16)	790	45	38,120
8. Naskaupi (U-4B)	Churchill (A-3A)	334	35	11,355

SOURCE: Energy, Mines and Resources 1985 permeability of the soil, volume of moisture in the soil prior to the precipitation event (antecedent soil moisture), surface storage capacity (vegetation, ponds and lakes) and evapotranspiration. Runoff collects into channels to become streamflow which increases in volume as it flows through the basin. In addition to runoff from the surrounding watershed, streamflow also consists of water derived from direct precipitation into the channel as well as a component of groundwater flow.

Annual runoff represents the amount of streamflow integrated over a one year period. It is represented as an average depth of water over the entire drainage basin (Fisheries and Environment Canada 1978). Variability in precipitation, evaporation and natural storage capacity results in changes in annual runoff. Map 2.7.2 shows the long-term average of the annual variations of runoff for the Northern Wetlands Study area.

Runoff is determined from streamflow records collected as part of Environment Canada's hydrometric network. The pattern of runoff for the study area reflects two conditions: 1) there is a net annual surplus of precipitation over storage, infiltration and evapotranspiration throughout the Northern Wetland Study area; and 2) the amount of runoff increases from west to east. The highest annual runoff occurs in southern Labrador which compares to the highest measured total annual precipitation (Map 2.3.5A).

Throughout most of the study area, total annual precipitation increases from northwest to southeast whereas annual runoff generally increases from west to east. For northern areas to contribute as much runoff as southern areas, while receiving less precipitation, evapotranspiration must be lower at the more northerly latitudes (see Section 2.3).

2.7.3 WATER BALANCE

Over long periods, moisture that is supplied by precipitation is 'balanced' by water losses due to evapotranspiration and runoff and water storage approaches zero (den Hartog and Ferguson 1975). This is known as the water balance which is defined by the equation:

$$(3) \quad P = R + E \pm \Delta S$$

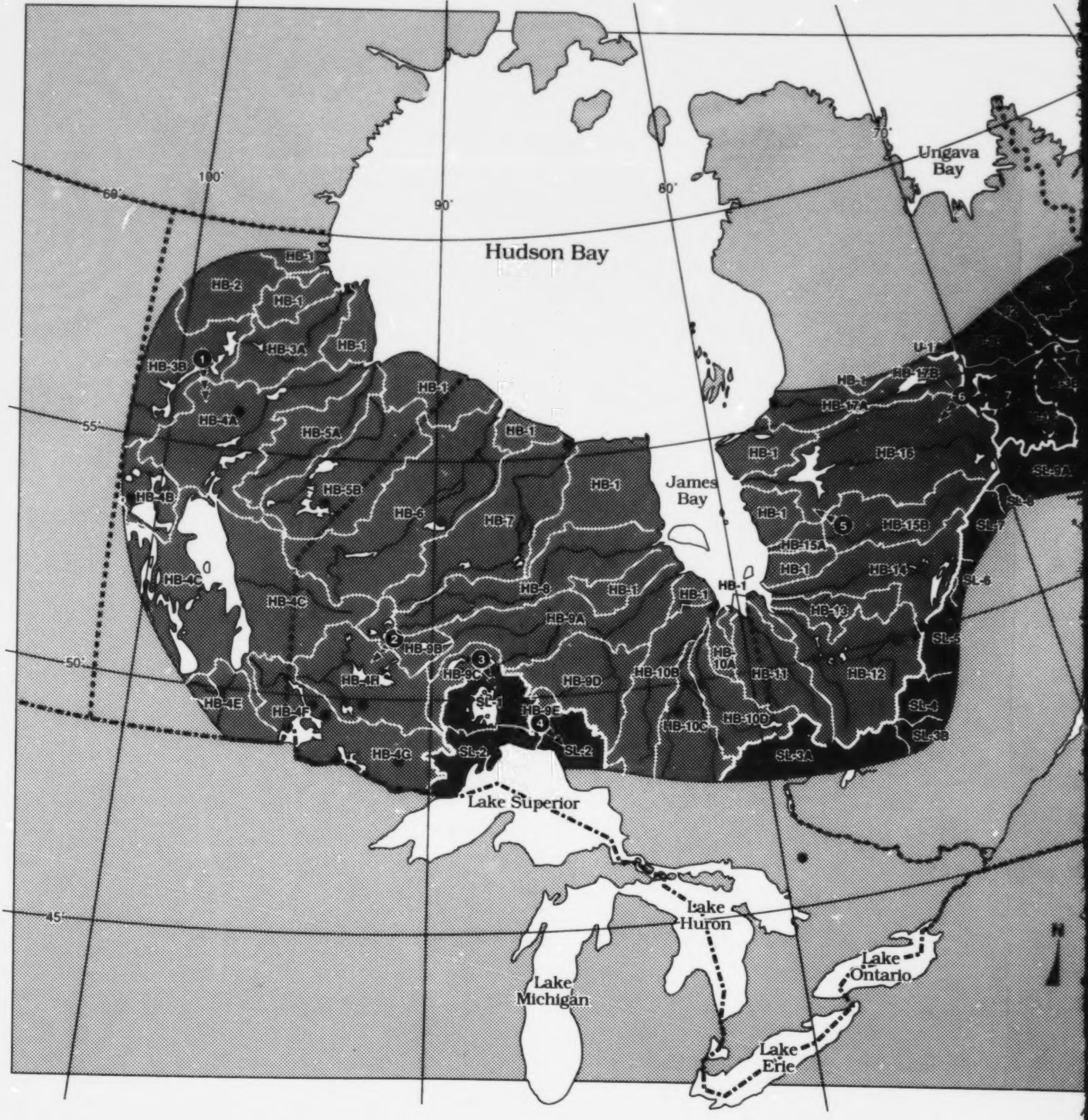
where P is precipitation, R is runoff, E is evapotranspiration and S is the change in storage (den Hartog and Ferguson 1975, 1978). Because storage is negligible over long time periods, the water balance can be determined by averaging long term records of the other factors. Precipitation and runoff are directly measurable but evapotranspiration must be estimated as a result of unsuitable instruments.

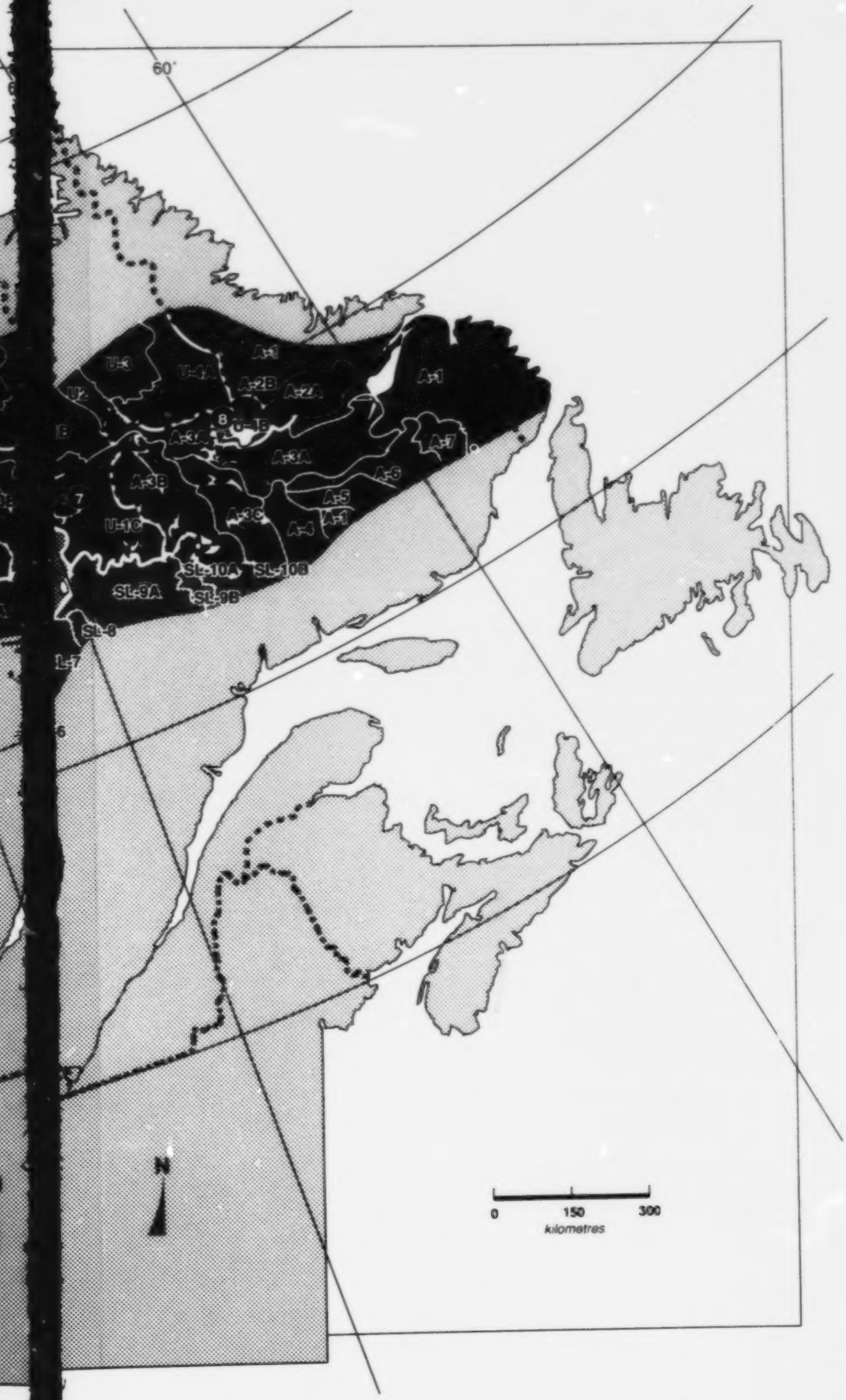
When deriving estimates of evapotranspiration from the water balance (equation 3) by using observed mean annual data for precipitation and runoff, the value for evapotranspiration is often too low for large areas considering moisture and energy availability (den Hartog and Ferguson 1975). For example, negative values of evapotranspiration were estimated for parts of Labrador.

Errors in the water balance calculation are likely due to inaccurate measurements of total precipitation. Rainfall can be underestimated by 7 to 14 percent while snowfall can be underestimated by 45 percent. The mean annual measured runoff (from gauging stations) is assumed to have no obvious measurement bias and is considered correct.

In order to accurately map components of the water balance for Canada, den Hartog and Ferguson (1975, 1978) determined mean annual precipitation, runoff and evapotranspiration for individual 10,000 km^2 grid cells. Precipitation was determined using data for the period 1941 to 1970. Runoff for each grid cell was determined from gauging stations and, where no stations were available, by interpolating data from Map 2.7.2. Evapotranspiration was determined from evaporation data measured with class A evaporation pans. The data provide an estimate of the mean annual evaporation from small lakes which is assumed to be close to the mean annual evapotranspiration from a fully vegetated surface with a sufficient water supply. This is referred to as potential evapotranspiration. Actual evapotranspiration can then be determined from a ratio of actual to potential evapotranspiration based on the surface cover within the grid cell. Surface cover types included water, forest, cropland, tundra, bog, rock and ice. Each was assigned a ratio between 1.0 and 0.1 (water, ice and bog were assigned a ratio of 1.0) which was applied to the potential evapotranspiration and weighted on the basis of percent cover within the grid cell.

All three components of the water balance equation were calculated and adjustments were made to the precipitation and evapotranspiration data (runoff was assumed to be accurate) in order to balance the equation. The derived precipitation and evapotranspiration are shown in Map 2.7.3.


Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60°
55°
50°
45°
N
HB-1
HB-2
HB-3A
HB-3B
HB-4A
HB-4B
HB-4C
HB-4E
HB-4F
HB-4G
HB-4H
HB-5A
HB-5B
HB-6
HB-7
HB-8
HB-9A
HB-9B
HB-9C
HB-9D
HB-9E
HB-10A
HB-10B
HB-10C
HB-10D
HB-11
HB-12
HB-13
HB-14
HB-15A
HB-15B
HB-16
HB-17A
HB-17B
U-1A
SL-1
SL-2
SL-3A
SL-3B
SL-4
SL-5
SL-6
SL-7
SL-8
SL-9A
1
2
3
4
5
6
7



map 2.7.1
NORTHERN WETLANDS STUDY AREA

Drainage Basins and Diversions

▨ **drainage to Hudson Bay (HB)**

▩ **drainage to St. Lawrence River (SL)**

■ **drainage to Atlantic Ocean (A)**

■ **drainage to Ungava Bay (U)**

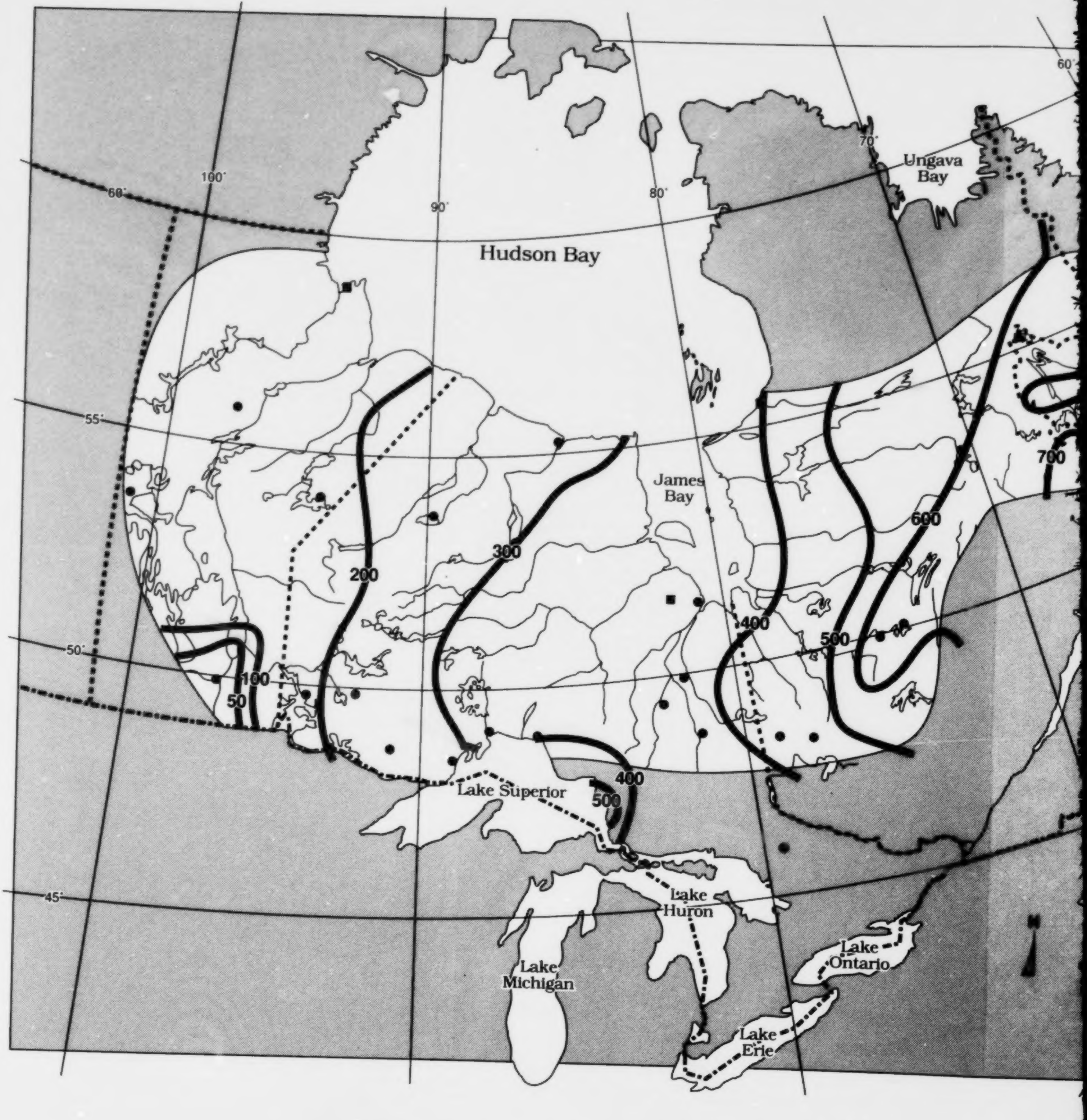
⑥ **diversion**

Note For more specific descriptions of basin annotations see Table 2.7.1

Information on the 8 diversions is provided in Table 2.7.2

Source
Drainage Basins, 1:7.5m. National Atlas of Canada
(Energy, Mines & Resources, 1985)

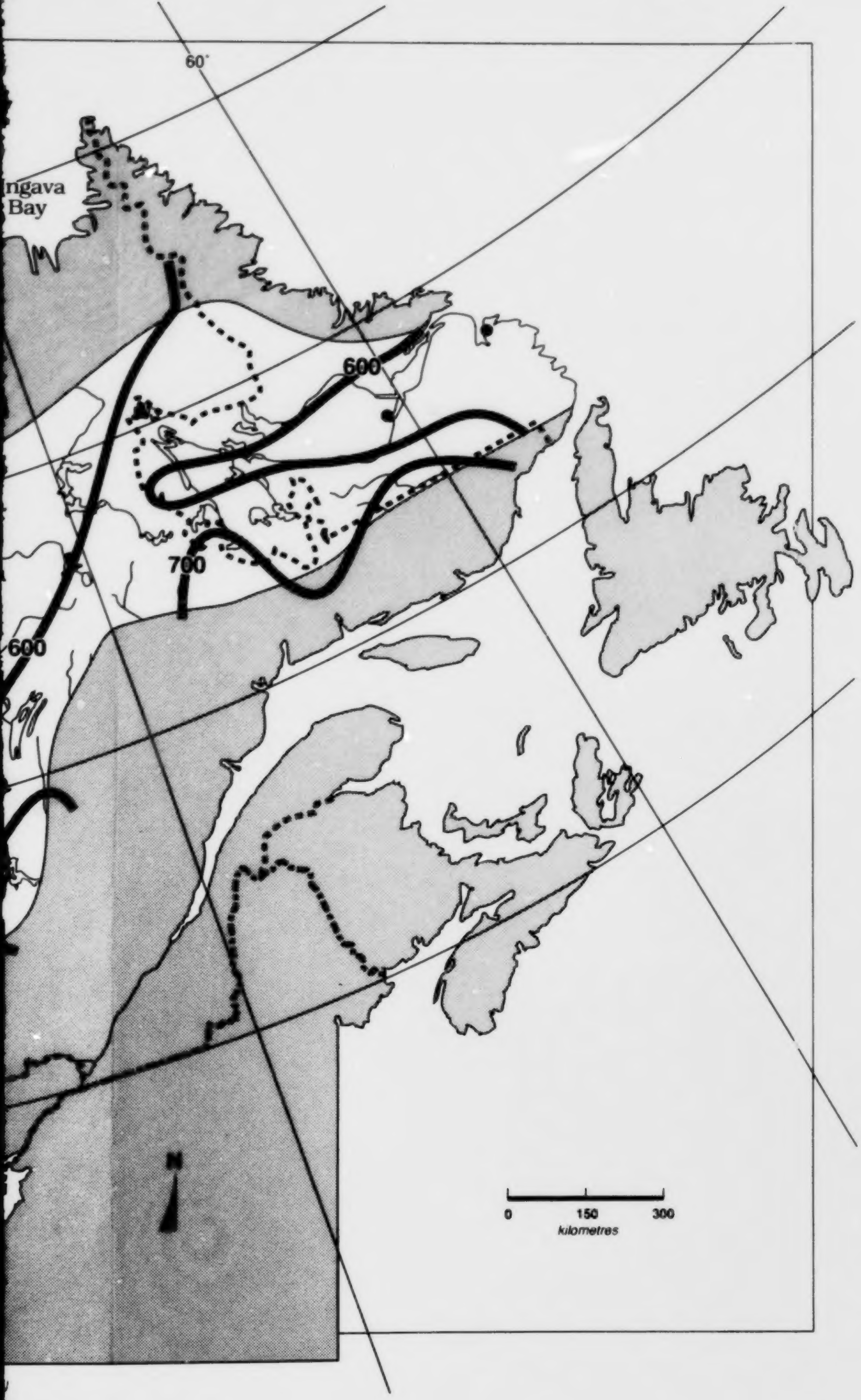
Projection: polar stereographic


60°
100°
90°
80°
70°
60°
Ungava Bay
Hudson Bay
55°
James Bay
700
600
200
300
400
500
50°
100
50
400
500
Lake Superior
45°
Lake Huron
Lake Ontario
Lake Michigan
Lake Erie
N

map 2.7.2

NORTHERN WETLANDS STUDY AREA

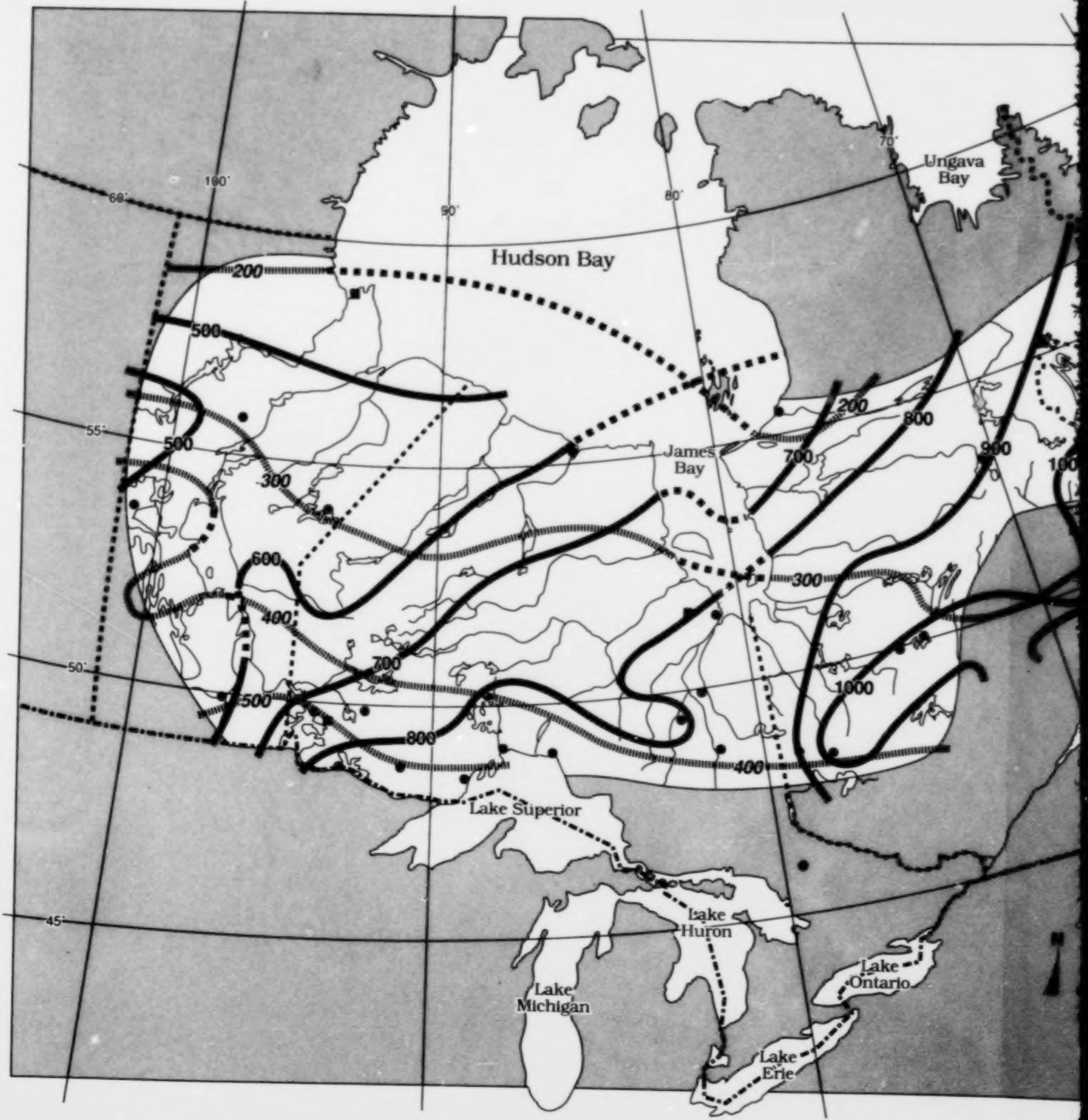
Annual Runoff



600 annual runoff (mm)

Source
Hydrological Atlas of Canada, 1:10 m.
(Fisheries and Environment Canada, 1978)

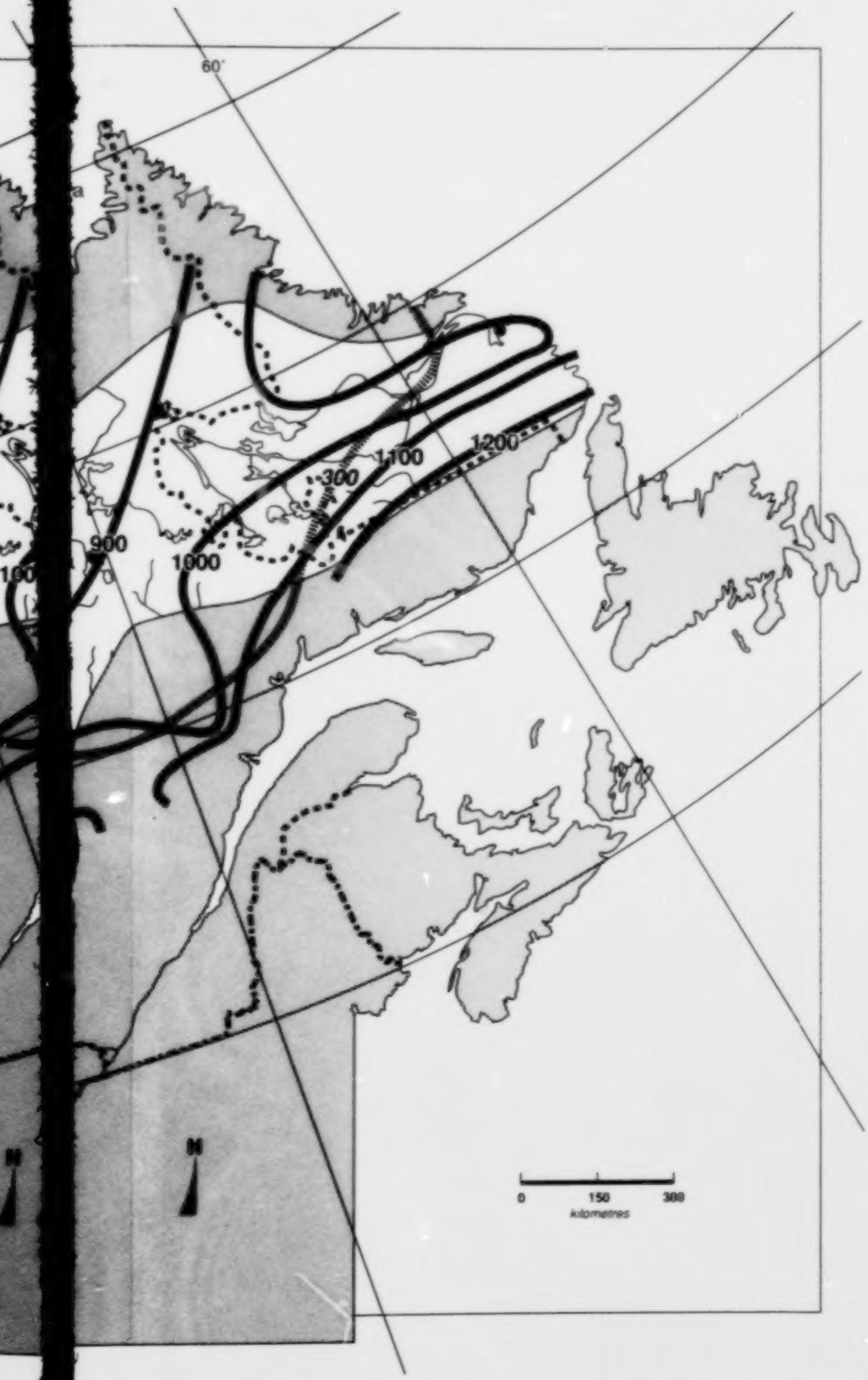
Projection: polar stereographic


Hudson Bay
Ungava Bay
James Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
60°
100°
90°
80°
70°
55°
50°
45°
200
500
500
300
600
400
700
500
800
200
800
700
900
300
1000
400

map 2.7.3

NORTHERN WETLANDS STUDY AREA

Water Balance - derived precipitation and evapotranspiration



━ annual derived precipitation (mm)

▥ annual derived evapotranspiration (mm)

Note: based on grid area estimates of precipitation, evaporation and runoff (den Hartog & Ferguson, 1975, 1978)

Source:
Hydrological Atlas of Canada, 1:10 m.
(Fisheries and Environment Canada, 1978)

Projection: polar stereographic

When compared to the measured precipitation in Map 2.3.5A, the derived precipitation is higher although the overall pattern of precipitation is similar (i.e., increasing from northwest to southeast). This is due to the adjustment factor which reflects the underestimation of precipitation by measuring instruments. It also reflects different periods of record for the precipitation data in Map 2.3.5A (1951-1980) as compared to Map 2.7.3 (1941-1970).

Derived evapotranspiration is shown to increase from north to south reflecting overall latitudinal climatic variation. This pattern would explain the north-south orientation of the runoff isolines even though the isolines for measured precipitation are predominantly oriented east-west (Section 2.7.2).

2.7.4 RIVER AND LAKE FREEZE-OVER AND ICE-FREE

Map 2.7.4 illustrates the average date of river (A) and lake freeze-over (B). Freeze-over represents the final stage of freezing when the water body is either completely frozen or at its maximum ice cover if it does not completely freeze. The average dates for rivers (C) and lakes to be ice-free (D) are also shown on Map 2.7.4. Ice-free represents the average date when the water body is completely free of ice. These maps are based on a minimum 5 years of observation recorded at weather stations operated by the Atmospheric Environment Service of Environment Canada (Allen 1978).

The isolines represent very generalized patterns of freeze-over and ice-free for lakes and rivers. Although based on observation, the sample population in any given area is small. The size and depth of lakes and the volume and speed of river flow affect the actual date for any given water body.

The pattern of freeze-up and break-up displays two primary characteristics: 1) rivers freeze later and thaw earlier than lakes and 2) freeze-up progresses from north to south. The freeze and thaw pattern of rivers is affected by flow in the channels. In fall, it takes longer for running water to freeze relative to lakes in the same area. River ice cover forms gradually from the shore outward. In spring, increasing air temperatures and under-ice flow result in ice cover in rivers breaking-up more quickly than ice cover in lakes at the same latitude.

The north-south progression of freeze-up (reversed for break-up) reflects the pattern of net radiation and air temperature (Section 2.3). The river and lake freeze-over isolines also show marked northward trends around Hudson Bay and toward the Atlantic. This pattern illustrates the moderating influence of these large water bodies in delaying the time of freeze-over.

The south to north progression of thawing is particularly significant for large northward flowing rivers. Rivers such as the Moose, Albany, Winisk and Severn thaw in a sequence from upstream to downstream. Thus, headwater reaches open first and begin to drain meltwater downstream toward the frozen lower reaches. Heavy snow cover in the watershed combined with a relatively rapid thaw often results in downstream flooding as river ice dams the onrushing meltwaters. This can result in serious flooding with consequent loss of life and damage to communities. Such a condition destroyed the village of Winisk near the shore of Hudson Bay in 1985. The entire community was rebuilt (Peawanuck) further upstream where higher river banks provide better protection.

2.7.5 WETLAND HYDROLOGY

2.7.5.1 GENERAL FACTORS

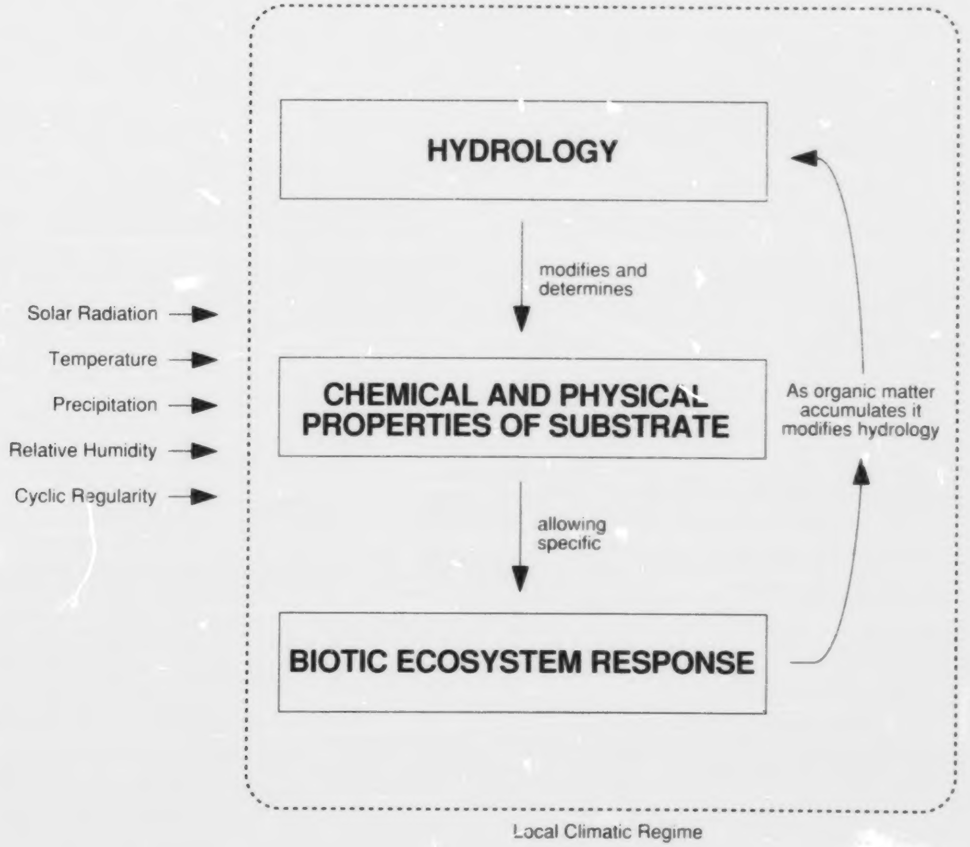
Gosselink and Turner (1978) developed a conceptual model of the role of hydrology in wetland ecosystems (Figure 2.7.1). In this model, hydrology acts as a control of wetland development. Carter *et al.* (1979) suggest that all natural wetland functions are a result of, or are closely related to, wetland hydrology.

The important attributes of the hydrologic regime with regard to wetland development were described by Gosselink and Turner (1978) as follows: the source and pathway of the water which determines its ionic composition; the velocity which affects turbulence and the ability of the water to carry suspended particulate matter; the renewal rate which describes the frequency of replacement of the water (a function of depth or volume, frequency of inundation, and velocity); and the timing or frequency of inundation and its regularity influence the potential for the system to mature. These attributes become modified as the wetland develops, particularly through the accumulation of peat material (Figure 2.7.1).

The role of wetlands within the hydrological cycle was once considered to be storage and low-flow (base flow) augmentation for surface streams and/or groundwater. Current research suggests that many more wetlands are groundwater discharge areas than recharge sources (Carter and Novitzki 1988). Uptake of water by vegetation and evapotranspiration in wetlands during the growing season would restrict streamflow or groundwater augmentation (Carter *et al.* 1979, Roulet

FIGURE 2.7.1

Conceptual model showing the role of hydrology in wetland ecosystems and the modification of hydrology by wetland processes (from Gosselink and Turner 1978).

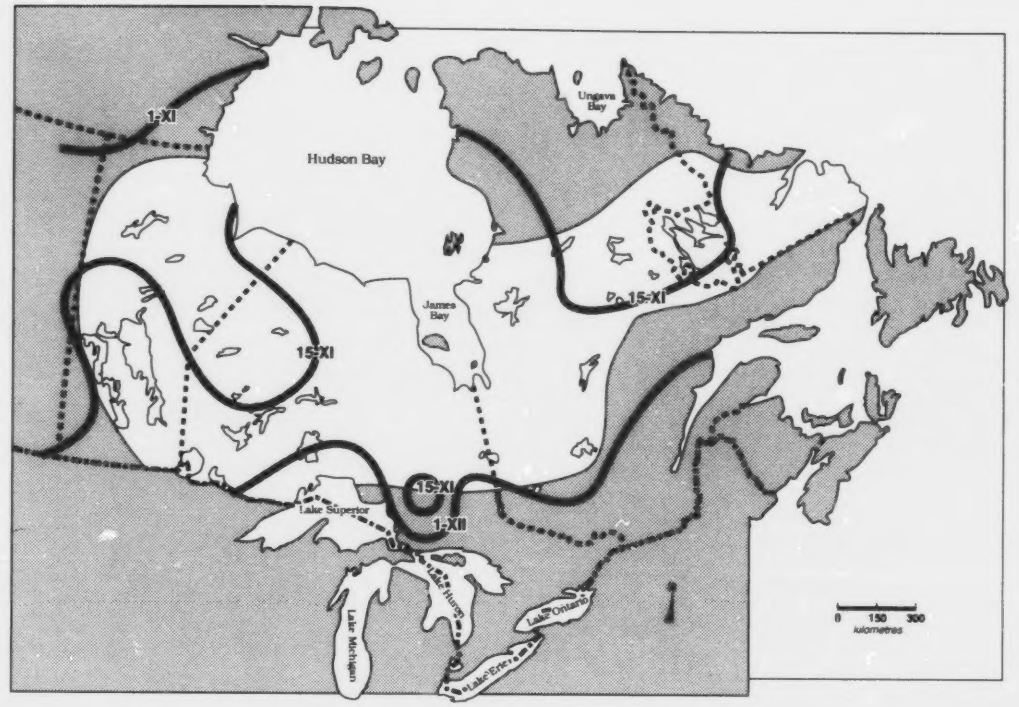


map 2.7.4

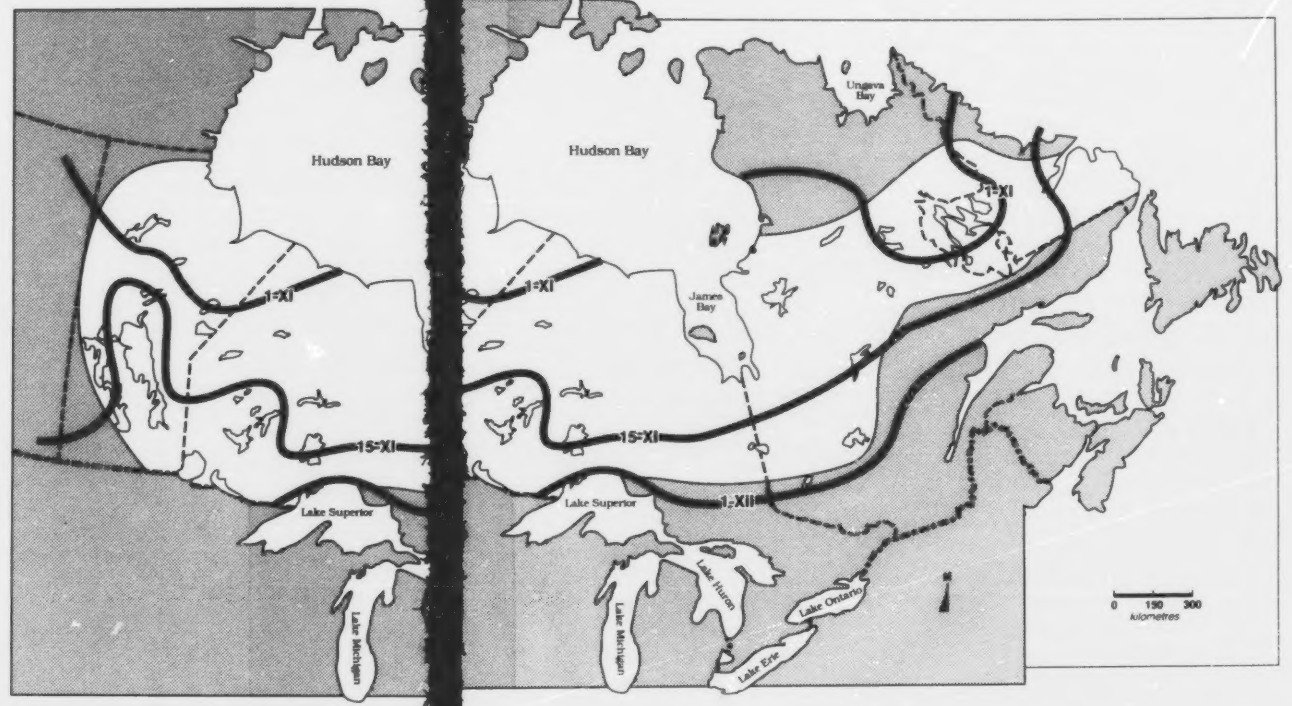
NORTHERN WETLANDS STUDY AREA

Mean dates of freeze-over and ice-free for lakes and rivers

15-XI mean freeze-over date or mean ice-free date

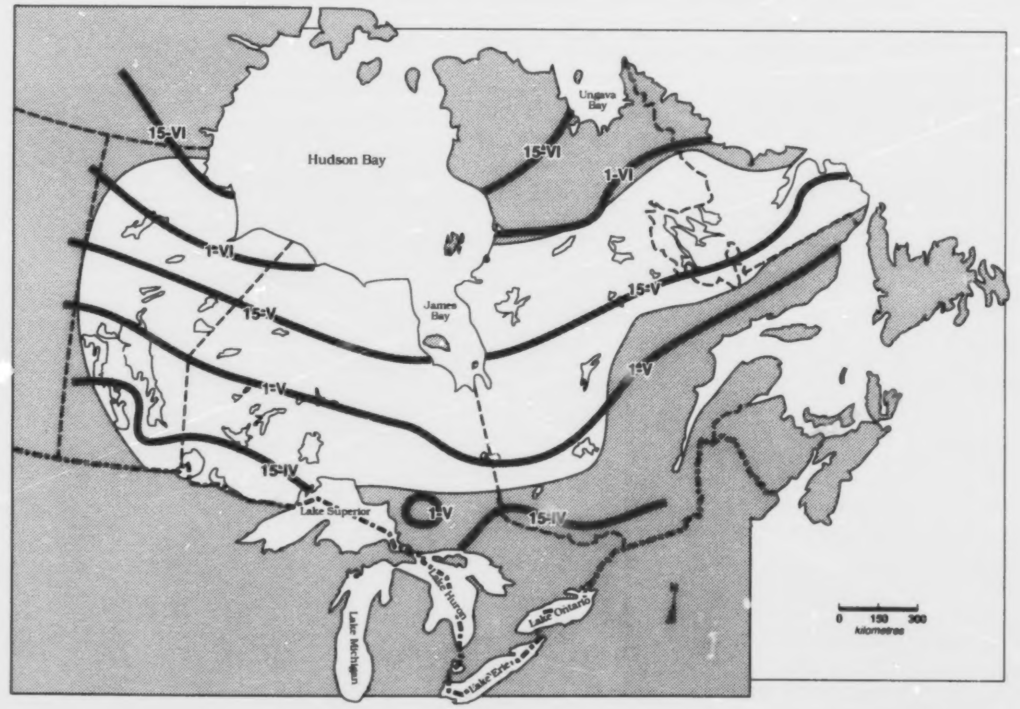


map 2.7.4 a River freeze-over

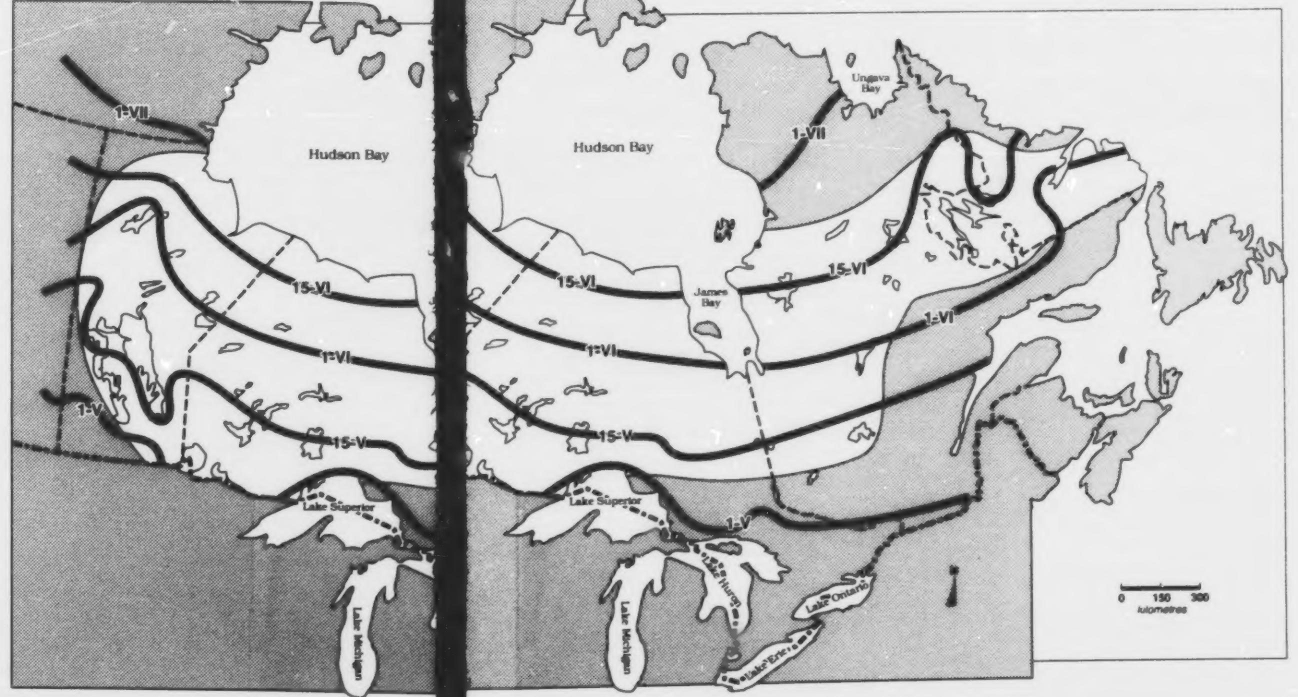


map 2.7.4 b Lake freeze-over

eeze-over



map 2.7.4 c River ice-free



map 2.7.4 d Lake ice-free

ce-free

Source:
Hydrological Atlas of Canada, 1:20 m.
(Fisheries and Environment Canada, 1978)

and Woo 1986). However, the hydrological role of wetlands is very complex and site-specific, thus, generalizations based on physiographic setting cannot be made (Carter and Novitzki 1988, Siegel 1988). Specific factors identified by Carter and Novitzki (1988) which affect wetland hydrology include:

1) the interrelationships between local, intermediate and regional groundwater tables;
2) position of the local water table;
3) geologic setting;
4) ratio of vertical to horizontal hydraulic conductivity (a function of wetland size, slope, peat accumulation and presence or absence of permafrost);
5) depth and width of the basin;
6) local slope and relief; and
7) the location of groundwater divides.

The accumulation of peat can completely reverse the hydrological regime over time, such that a wetland which formerly received groundwater (i.e., groundwater discharge area) becomes a wetland which contributes to groundwater supplies (i.e., groundwater recharge). This occurs, for example, during the formation of large peatland complexes which originate as swamps or fens (minerotrophic) but develop into ombrotrophic raised bogs which receive all nutrients from precipitation (Moore and Bellamy 1974).

2.7.5.2 BASIN FLOW REGIME

The hydraulic conductivity of peat decreases exponentially with increasing depth due to greater decomposition and compaction at depth (Goode *et al.* 1977). The majority of the subsurface flow in peatlands thus takes place in the upper 0.5 m (Woo and Heron 1987a).

Although peatlands have a large water storage capacity, the absorptive capacity of the organic material limits their ability to provide base flow to streams even during extended drought conditions. Goode *et al.* (1977) note that runoff from peatlands is considerably reduced when the water table falls to a level of more pronounced humification. This can occur at depths from 8 to 25 cm below the surface. Goode *et al.* (1977) cite one study which discovered a complete absence of runoff when the water table reached a depth of 20 cm. Reduced runoff at these depths is due to lower hydraulic conductivity as a result of more pronounced decomposition of the peat material. The type of peat (moss or sedge) does not affect the conductivity once decomposition reaches 5 on the von Post scale (a value of 10 represents the most decomposed stage). Once runoff has ceased from these peatlands, further lowering of the water table is accomplished only by evapotranspiration (Goode *et al.* 1977).

The streamflow regime of basins containing wetlands have been investigated in Temperate (Taylor and Pierson 1985; Bay 1967, 1969), Sub-arctic (Price and Woo 1988, Woo and Heron 1987a) and Arctic (Roulet and Woo 1986, 1988) latitudes of eastern North America. In temperate latitudes the major control on the basin hydrograph is the relationship between the wetland and the regional groundwater system and the saturation state of the wetland prior to events such as snowmelt and summer storms. In more northerly latitudes these factors, along with the duration of seasonal frost (especially in Sub-arctic wetlands) and the presence of permafrost, are important.

Conditions which limit the storage capacity of the wetland tend to favour event-responsive hydrographs from basins containing wetlands. South of the discontinuous permafrost zone, this is caused primarily by high antecedent saturation of the wetland as a result of a high regional water table and/or previous precipitation events (Taylor and Pierson 1985). Thick peat accumulation provides storage capacity which can attenuate flows of individual storm events but tends to have little influence on surface runoff yields on a seasonal or annual basis (Bay 1967, 1969).

In Sub-arctic and Arctic regions the presence of late seasonal frost, such as occurs under the more densely forested areas (Cowell *et al.* 1978, Woo and Heron 1987a), and permafrost also limit the storage capacity of wetlands and enhances event-responsive streamflow. Roulet and Woo (1988) noted that, although the presence of organic soil layers in northern wetlands can provide a significant amount of storage capacity, the effect is only temporary. They observed that 70 percent of the total measured basin flow was released within two weeks of the initiation of streamflow in an arctic basin located near Baker Lake, Northwest Territories. Roulet and Woo (1988) concluded that the presence of frozen soils throughout the entire basin reduces the spatial contrast of variable hydrological systems (i.e., mixed wetland and upland systems).

Woo (1988) proposed a 'wetland streamflow regime' for Arctic and Sub-arctic regions on the basis of these and other studies. He noted that the earlier concept of the 'muskeg regime' presented by Church (1974) was based on too small a data set and was not representative of most northern wetlands. The muskeg regime of Church (1974) was one in which flood flows within peatlands are greatly attenuated because of the large water retaining capacity of peatland vegetation and due to the high resistance to runoff presented by the vegetation and its irregular surface. The northern wetland flow regime of Woo (1988) attributes the attenuation of streamflow during the dry season to the presence of a frost table close to the surface and low hydraulic gradients resulting in retention of water in ponds and organic soils. A large spring freshet is produced by abundant snowmelt and enhanced by low infiltration into the frozen ground. The exception is where winter snowfall is so low that the spring snowmelt is insufficient to generate overland flow.

Price and Woo (1988) also found that the hydrological regime postulated by Church (1974) did not explain the water balance or hydrological regime of shallow-peat coastal marshes. In a detailed study of a sub-arctic coastal marsh located in the Hudson Bay Lowland (southern James Bay), Price and Woo (1988) found that snowmelt and rainfall are transmitted quickly through the system in spite of the large total water storage capacity. The only exception occurred following long dry periods when evaporation created a large water deficit.

It is not certain if the same streamflow regime holds for wetland basins with deep peats and minimal upland areas. In the case of large sub-arctic peatland complexes, such as in portions of the continuous wetlands of the Hudson Bay Lowland, it can be postulated that Church's (1974) muskeg regime may be more representative. In these areas, particularly outside the zones of continuous or widespread permafrost, the lack of normal surface streams, a regionally low gradient and thick peat material could provide considerable water retaining capacity even though regional water tables are high. Large inputs to the peatland in the form of rain, snowmelt or contributions from deeper aquifers might result in a change in volume of the peat mass, flooding of the peat surface and/or even a quasi-floating of the peat mass. In any case, there would likely be a less immediate response in the hydrologic regime of rivers draining the peatland than for rivers draining mixed watersheds or small streams draining coastal marshes.

2.7.5.3 RIVER BREAK-UP CONSIDERATIONS

Woo and Heron (1987b) investigated the break-up pattern of small sub-arctic rivers along the coast of James and Hudson Bays. They note that the control of break-up varies between temperate and sub-arctic rivers. The break-up of rivers in temperate regions is controlled primarily by river ice whereas in sub-arctic regions, channel snow cover is more important. The presence of large areas of wetlands common to the sub-arctic is considered to be an important factor affecting break-up due to seasonally frozen ground, flat terrain and snow and ice conditions which combine to produce complex hydrological responses during the break-up season, particularly in small catchments.

The specific break-up sequence for a small river draining wetlands in the Hudson Bay Lowland was described by Woo and Heron (1987). They note that snow conditions dominate the break-up sequence until the underlying ice layer is exposed. The early portion of the sequence is characterized by a large amount of snow melt draining from the wetland. Ponds are impounded behind snow dams created by compacted snow in the channel. This accentuates flooding as the dam is breached causing slushing and removal of the residual snow cover. At this point channel ice conditions become most important to the river break-up process.

2.7.6 REFERENCES

Allen, W.T.R. 1978. Freeze-up and break-up of rivers and lakes. Text prepared for Plate 19 *In. Hydrological Atlas of Canada*. Supply and Services Canada, Ottawa, Ontario.

Bay, R.R. 1967. Factors influencing soil moisture relationships in undrained, forested bogs. *In. Forest Hydrology*. W.E. Sopper and H.W. Lull (eds), Pergamon: 335-343.

Bay, R.R. 1969. Runoff from small peatland watersheds. *J. Hydrol.*, 9: 90-102.

Carter, V. and R.P. Novitzki. 1988. Some comments on the relation between groundwater and wetlands. *In. The Ecology and Management of Wetlands*. Volume 1, D.D. Hook and Others (eds), Timber Press, Portland, OR: 68-86.

Carter, V., M.S. Bedinger, R.P. Novitzki and W.O. Wilen. 1979. Water resources and wetlands. *In. Wetland Functions and Values: The State of Our Understanding*. P.E. Greeson, J.R. Clark, J.E. Clark (eds), American Water Resources Assoc., Minneapolis, MN, Tech. Pub. TPS79-2:344-376.

Chow, Ven T. 1964. *Handbook of Applied Hydrology*. McGraw-Hill Book Co., Inc., Toronto.

Church, M. 1974. Hydrology and permafrost with reference to northern North America. Proc. Workshop Seminar on Permafrost Hydrology, J. Demers (ed.), Can. National Com., International Hydrological Decade, Environment Canada, Ottawa, Ontario: 7-20.

Cowell, D.W., J.K. Jeglum and J.C. Merriman. 1978. Preservation of seasonal frost in peatlands, Kinoje Lakes, southern Hudson Bay Lowland. Proc. 3rd Int. Conf. Permafrost, Edmonton Alta: 453-459.

den Hartog, G. and H.L. Ferguson. 1975. National water balance maps of evapotranspiration and precipitation. Proc. Canadian Hydrology Symposium-75, National Research Council, Ottawa, Ontario: 512-526.

den Hartog, G. and H.L. Ferguson. 1978. Water balance—derived precipitation and evapotranspiration. Text prepared for Plate 25, *In. Hydrological Atlas of Canada*. Supply and Services Canada, Ottawa, Ontario.

Energy, Mines and Resources. 1985. *The National Atlas of Canada*. 5th Edition, Energy, Mines and Resources Canada, Ottawa, Ontario.

Fisheries and Environment Canada. 1978. *Hydrological Atlas of Canada*. Supply and Services Canada, Ottawa.

Goode, D.A., A.A. Marsan and J.-R. Michaud. 1977. Water resources. *In. Muskeg and the Northern Environment in Canada*. N.W. Radforth and C.O Brawner (eds), U. Toronto Press, Toronto, Ontario.

Gosselink, J.G. and R.E. Turner. 1978. The role of hydrology in freshwater wetland ecosystems. *In. Freshwater Wetlands: Ecological Processes and Management Potential*. R.E. Good, D.F. Whigham, R.L. Simpson (eds), Academic Press, NY: 63-78.

Gray, D.M. 1970. Handbook on the Principles of Hydrology. Secretariat, Canadian National Committee for the International Hydrological Decade. National Res. Coun. Can., Ottawa, Ont.

Moore, P.D. and D.J. Bellamy. 1974. *Peatlands*. Springer-Verlag, New York Inc: 221p.

Price, J.S. and M.K. Woo. 1988. Studies of a Sub-arctic coastal marsh: I. Hydrology. *J. Hydrology*, 103: 275-292.

Roulet, N.T. and M.K. Woo. 1986. Hydrology of a wetland in the continuous permafrost region. *J. Hydrol.*, 89: 73-91.

Roulet, N.T. and M.K. Woo. 1988. Runoff generation in a low arctic drainage basin. *J. Hydrol.*, 101: 213-226.

Siegel, D.I. 1988. A review of the recharge-discharge function of wetlands. *In. The Ecology and Management of Wetlands*. D.D. Hook and Others (eds), Timber Press, Portland, OR: 59-67.

Taylor, C.H. and D.C. Pierson. 1985. The effect of a small wetland on runoff response during spring snowmelt. *Atmos.-Ocean*, 23(2): 137-154.

Woo, M.K. 1988. Wetland runoff regime in northern Canada. Proc. V, International Conf. Permafrost, Trondheim, Norway, August 1988, vol. 1: 644-649.

Woo, M.K. and R. Heron. 1987a. Effects of forests on wetland runoff during spring. Proc. Symp. Forest Hydrology and Watershed Manag., Vancouver, B.C., August, 1967: 297-307.

Woo, M.K. and R. Heron. 1987b. Breakup of small rivers in the Sub-arctic. *Can. J. Earth Sci.*, 24(4): 784-795.

2.8 VEGETATION

The map of vegetation regions for the Northern Wetlands Study area (Map 2.8.1) is taken from Rowe (1972) as modified by Clayton *et al.* (1977). Climatic variability within regions is generally less than between regions. As a result, similar landform components within a particular region will display a uniformity in vegetation physiognomy (i.e., structure such as tree, shrub, grass and moss layers) and in the composition of dominant species (Rowe 1972).

There are five vegetation regions within the study area. Each region has been subdivided by Rowe (1972) into Forest Sections which are shown on Map 2.8.1. The Sections and Regions are based primarily on upland vegetation communities. They are included in this document to provide a more complete overview of the ecological setting for the eastern North American wetlands. Wetland vegetation is considered only where wetlands occupy major portions of Forest Sections such as in the Hudson Bay Lowland. The dominant vegetation species associated with characteristic wetlands of the study area will be discussed in more detail in Chapter 3.

The Tundra and Boreal Forest Transition and the Boreal Forest Regions occupy over 90 percent of the Northern Wetlands Study area. The Southeastern Mixed Forest (Great Lakes—St. Lawrence Forest Section) lies along the extreme southern boundary of the study area between Winnipeg and Lake Superior. Small portions of the True Prairie Grassland and Boreal Forest and Grassland Transition Regions occur in the southwestern portion of Manitoba.

The concept of productive vs non-productive woodland used in this discussion is based on the definition provided by Clayton *et al.* (1977). Productive woodland has over 25 percent crown cover and trees are greater than 6 m in height. Productivity on these lands will generally be greater than 2 m^3/ha per year. Non-productive woodland is land which does not meet any of these criteria.

2.8.1 TUNDRA AND BOREAL FOREST TRANSITION

This vegetation region is the most northerly within the Northern Wetlands Study area. It stretches across northern Manitoba, through the Hudson Bay Lowland in Ontario and Québec, and across central Québec and southern to central Labrador. To the north of this region in Québec and Labrador is the treeless Bush or Scrub Tundra (Clayton *et al.* 1977).

This region includes elements of both the Tundra and Boreal Forest Regions. Tundra vegetation includes shrubs such as willows (*Salix* spp.), alder (*Alnus crispa*), dwarf birch (*Betula glandulosa*) and Labrador tea (*Ledum groenlandicum*). These shrubs occur in association with herbaceous undergrowth such as blueberry (*Vaccinium uliginosum*), bog cranberry (*Vaccinium vitis-idaea*), and crowberry (*Empetrum nigrum*). More exposed locations including rockland and upland mineral sites are dominated by lichen-moss tundra with lichen species such as reindeer moss (*Cladonia* spp.), sedges (*Carex* spp.), low willows (*Salix* spp.) and avens (*Dryas* spp.).

Boreal transition woodlands characteristic of this region are mainly non-productive conifer stands dominated by open, stunted black spruce (*Picea mariana*) accompanied by alders (*Alnus* spp.), willows (*Salix* spp.) and tamarack (*Larix laricina*) in the wetter sites. Boreal mixed woods occur in areas which have less harsh climatic conditions and richer soils, such as along river levées and in valleys. These include white spruce (*Picea glauca*), balsam fir (*Abies balsamifera*), trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*). Jack pine (*Pinus banksiana*) may occur on well-drained coarse textured soils in some sections of the region.

2.8.2 BOREAL FOREST

The Boreal Forest Region occupies the central and southern portion of the Northern Wetlands Study area. It is roughly equal in area to the Tundra and Boreal Forest Transition Region. The southern border of the Boreal Forest merges with the Southeastern Mixed Forest in Ontario and western Québec.

This region is dominated by generally productive conifer forests. Black and white spruce (*Picea mariana* and P. *glauca*) are the main tree species (Clayton *et al.* 1977, Rowe 1972). Other characteristic conifers within the study area include tamarack (*Larix laricina*), balsam fir (*Abies balsamifera*) and jack pine (*Pinus banksiana*). Deciduous trees which are common throughout the area include white birch (*Betula papyrifera*), aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*). Aspen is particularly common where the boreal forest grades into the Boreal Forest and Grassland Transition Region. Near the Boreal Forest - Southeastern Mixed Forest Region boundary considerable mixing of species from the two regions occurs. These include white and red pines (*Pinus strobus* and *P. resinosa*), yellow birch (*Betula lutea*), sugar maple (*Acer saccharum*), black ash (*Fraxinus nigra*) and eastern white cedar (*Thuja occidentalis*).

Black spruce and tamarack are the species most common in forested wetland sites throughout most of this region. These sites are generally non-productive, particularly where organic soils (peatlands) form the substrate. Growth in these areas is limited by excess moisture, prolonged cold or frozen conditions (Clayton *et al.* 1977). Tree species common to forested swamps in more southerly locations include black ash and white cedar.

2.8.3 SOUTHEASTERN MIXED FOREST (Great Lakes—St. Lawrence Forest)

This vegetation region consists of mixed forests characterized by white and red pines (*Pinus strobus* and *P. resinosa*), eastern hemlock (*Tsuga canadensis*) and yellow birch (*Betula lutea*). Species characteristic of the Boreal Forest intermix, particularly in the study area. These include jack pine (*Pinus banksiana*), particularly on sandy to coarse-textured soils, poplars (*Populus* spp.), and white birch (*Betula papyrifera*). These forests are generally productive.

Non-productive growth of black spruce and tamarack occur on peatland sites within this region. Mineral soil wetlands may have white cedar (*Thuja occidentalis*), black ash (*Fraxinus nigra*) or red maple (*Acer rubrum*).

2.8.4 GRASSLANDS

Small portions of the True Prairie and the Boreal Forest and Grassland Transition Regions occur within the extreme southwestern portion of the Northern Wetlands Study area. Tree growth is restricted in these regions due to moisture limitations. Climatic conditions are most favourable for the growth of a productive grass cover.

Tree growth increases toward the north where the grasslands grade into the boreal forest. Grasses characteristic of the Boreal Forest and Grassland Transition are rough fescue (*Festuca scabrella*), dryland sedges (*Carex* spp.), wheatgrasses (*Agropyron* spp.), porcupine grass (*Stipa spartea*) and June grass (*Koeleria cristata*). The True Prairie Region is dominated by spear grasses (*Stipa* spp.), blue stem grasses (*Andropogon* spp.), panic grasses (*Panicum* spp.), Indian grass (*Sorghastrum* spp.) and prairie dropseed (*Sporobulus* spp.).

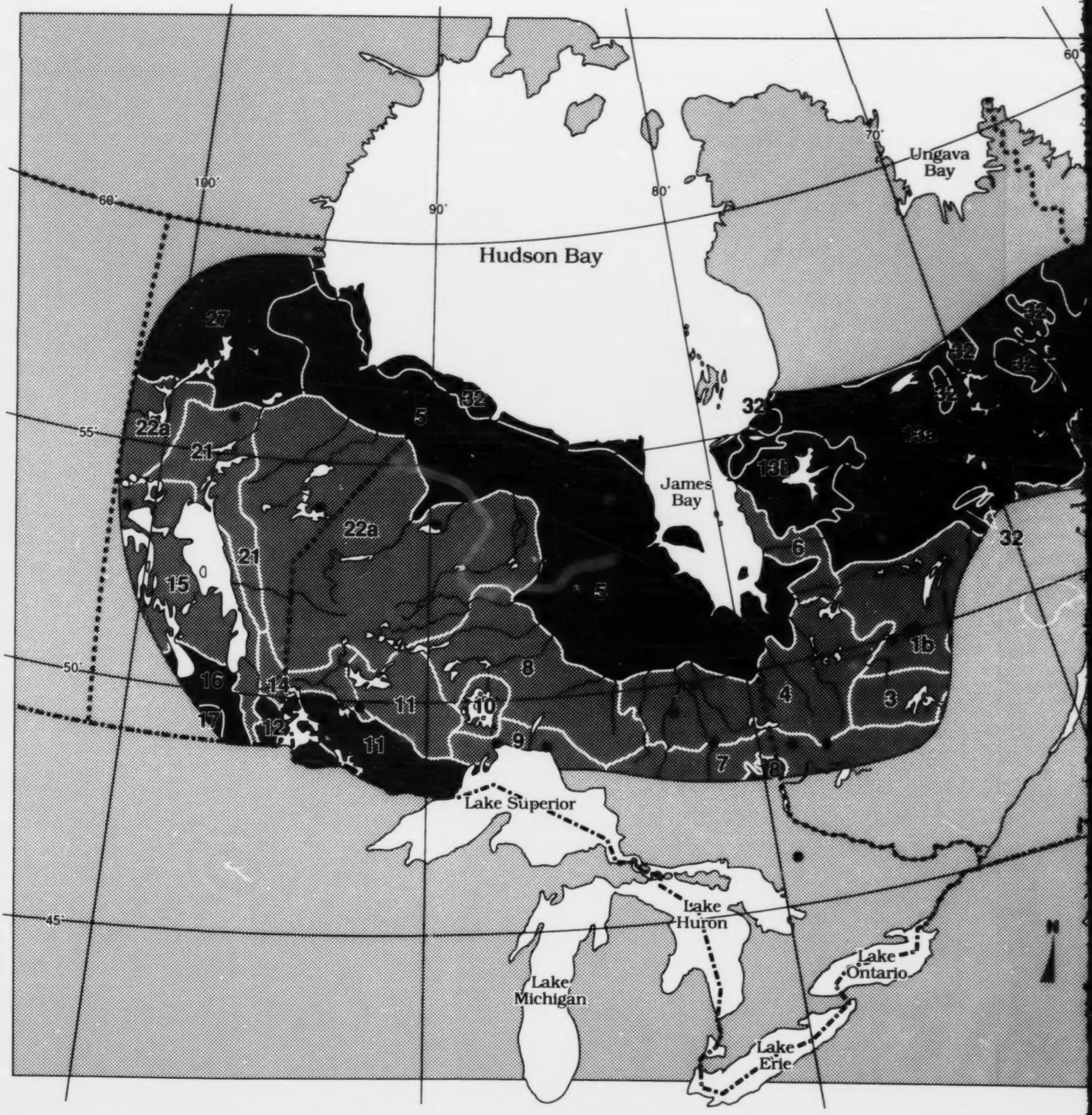
Trees occur in the Boreal Forest and Grassland Transition Region as groves or clumps. Aspen (*Populus tremuloides*) and bur oak (*Quercus macrocarpa*) are dominant on dry sites and balsam poplar (*P. balsamifera*) on wetter sites. In the True Prairie Region, native trees are confined to stream banks and include American elm (*Ulnus americana*), Manitoba maple (*Acer negundo*) and green ash (*Fraxinus pennsylvanica*).

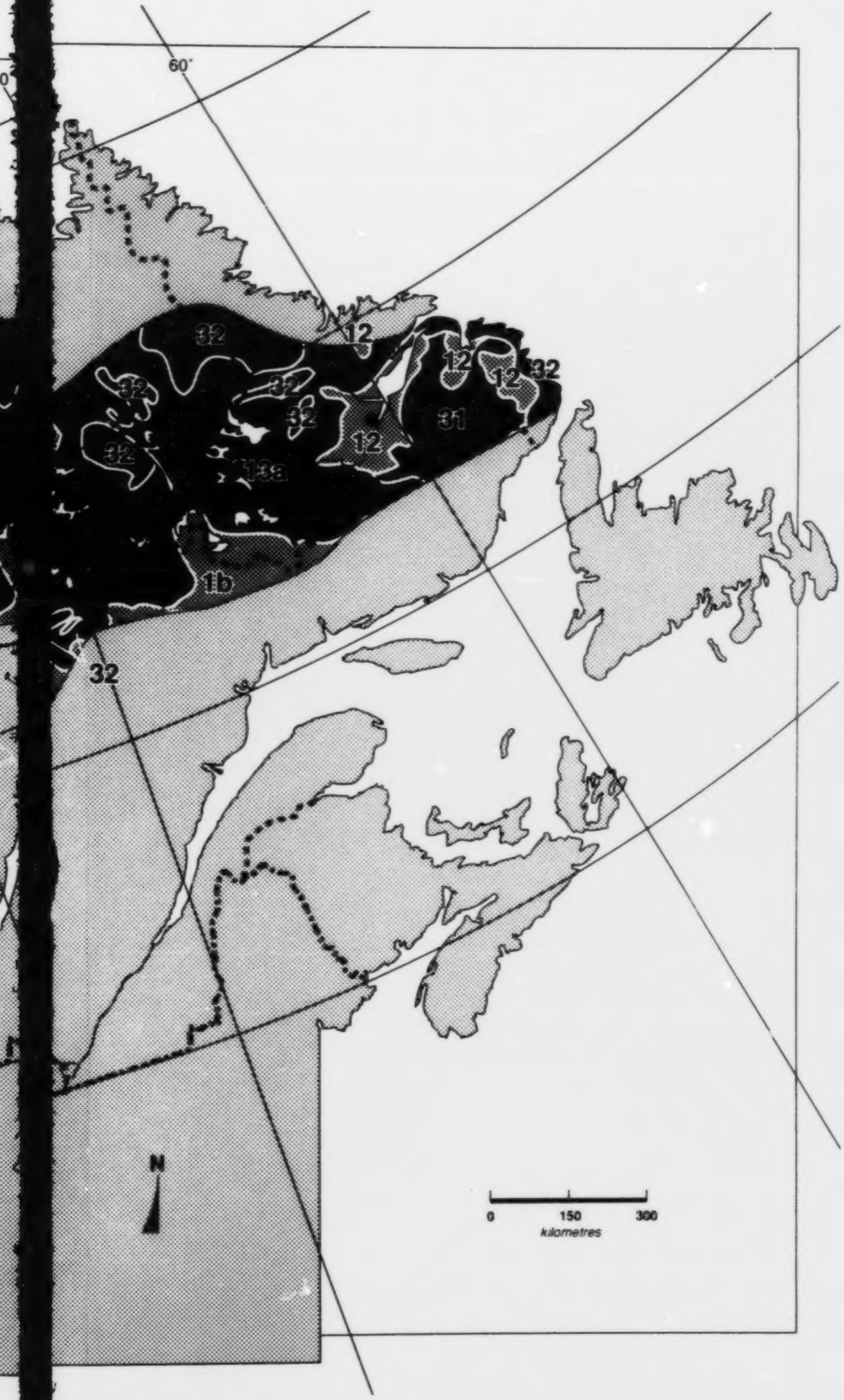
Wetlands which occur in the Grasslands Region are characteristically treeless, consisting of aqueous or submerged communities in sloughs or prairie potholes. Characteristic vegetation includes pondweeds (*Potamogeton* spp.), water-milfoil (*Myriophyllum* spp.), bullrushes (*Scirpus* spp.), cattails (*Typha latifolia*) and spangle top (*Scolochloa festucacea*). Vegetation communities in the slightly drier edges of these wetlands are dominated by sedge meadows with sedges (*Carex* spp.) and reedgrass (*Calamogrostis* spp.) and shrub fringes (*Salix* spp.).

2.8.5 REFERENCES

Clayton, J.S., W.A. Ehrlich, D.B. Cann, J.H. Day and I.B. Marshall. 1977. Soils of Canada. The Canada Soil Committee and The Soil Research Institute, Agriculture Canada, Ottawa, Ontario. 2 vol with accompanying maps.

Rowe, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Publication No. 1300, Ottawa, Ontario: 172p. plus fold-out map.


Hudson Bay
James Bay
Ungava Bay
Lake Superior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
100°
90°
80°
70°
60
60°
55°
50°
45°
27
22a
21
22a
21
15
0
16
17
14
12
11
11
10
9
8
5
5
32
32
32
32
32
32
32
13a
13b
6
1b
3
4
7
8
N



map 2.8.1
NORTHERN WETLANDS STUDY AREA

Vegetation Regions and Forest Sections

Regions

▨ Boreal Forest

1b	Chibougamau - Natashquan	10	Nipigon
3	Gouin	11	Upper English River
4	Northern Clay ('Clay Belt')	12	Hamilton & Eagle Valleys
6	East James bay	14	Lower English River
7	Missinaibi - Cabonga	15	Manitoba Lowlands
8	Central Plateau	21	Nelson River
9	Superior	22a	Northern Coniferous

▩ Southern Mixed Forest
(Great Lakes - St. Lawrence Forest)

11	Quetico	12	Rainy River

■ Tundra and Boreal Forest Transition

5	Hudson Bay Lowlands	27	Northwestern Transition
13a	Northeastern Transition	31	Newfoundland - Labrador Barrens
13b	Fort George	32	Forest - Tundra

■ Grasslands

16	Aspen - Oak (Boreal forest - Grassland Transition)	17	True Prairie

13a Forest sections indicated by numbers

Source
Forest Regions of Canada, 1:6.3 m (Rowe, 1972)
Vegetation Regions of Canada, 1:25 m (Clayton et al., 1977)

Projection: polar stereographic

CHAPTER 3

WETLAND REGION DESCRIPTIONS

WETLAND REGION DESCRIPTIONS

3.1 WETLAND DISTRIBUTION AND WETLAND REGIONS

Wetlands are particularly common in the Canadian landscape where a large variety of wetland types have formed as a result of Canada's wide range of climatic and physiographic conditions (Tarnocai 1988). The most recent estimate of the area of wetlands (including peatlands) in Canada is 127.2 million ha or 14 percent of the total land area. Peatlands occupy 111.3 million ha or 12 percent of the total land area of Canada (Zoltai 1988, Tarnocai 1984). Although occurring in all latitudes and climates, wetlands tend to be least abundant in the Prairies and High Arctic (Tarnocai 1984) and most abundant in mid latitudes, particularly the Boreal and Sub-arctic regions. Sjörs (1961) notes that "...by far the greater part of the total peat area of the world is within the Boreal zone". His Boreal zone includes both the Sub-arctic and Boreal Wetland Regions as defined by the National Wetlands Working Group (1986).

Map 3.1.1 highlights the wetland regions and distribution of wetlands within the Northern Wetlands Study area. The occurrence of wetlands ranges from sporadic (covering less than 51 percent of land cover), particularly in upland areas and southern and eastern Canadian Shield areas, to widespread and continuous. Widespread wetlands (51 to 75 percent of the land area) are found on glaciolacustrine deposits of northern Manitoba, northeastern and northwestern Ontario and west central Québec. Continuous wetland areas (greater than 75 percent of the land area) occur on glaciolacustrine deposits surrounding Lake Winnipeg and on the glaciomarine sediments of the Hudson Bay Lowland in portions of Manitoba, Ontario and Québec.

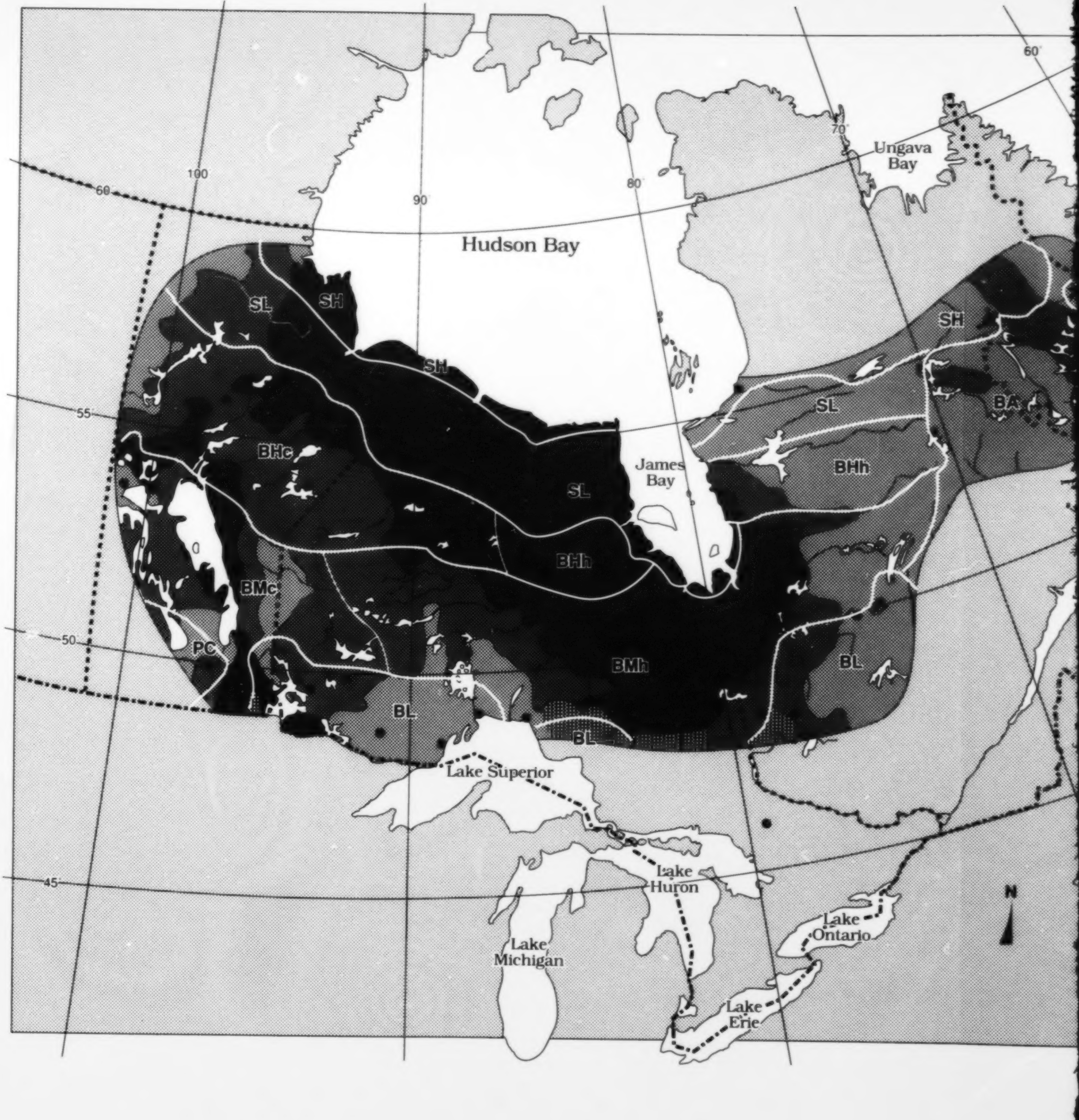
The Northern Wetlands Study area includes approximately 50 percent of the peatland area and 55 percent of the total volume of peat estimated for Canada[1]. Within this area are nine wetland regions (Map 3.1.1) which are broadly grouped into 4 climatic zones including the Sub-arctic (High, Low and Atlantic Sub-arctic Wetland Regions), Boreal (High, Mid, Low and Atlantic Boreal Wetland Regions), Prairie (Continental Prairie Wetland Region) and Mountain (Eastern Mountain Wetland Region). The Prairie and Mountain regions occupy only small portions of the study area and are not discussed further. Wetland regions are areas which have relatively similar wetland types based on their biotic and physical characteristics (Zoltai 1988). Temperature and precipitation gradients were used to define the climatic zonations. The Sub-arctic and Boreal wetland regions within the Northern Wetlands Study area are described under the following Subsections: Environmental Setting, Wetland Characteristics, Wetland Types and Toposequence.

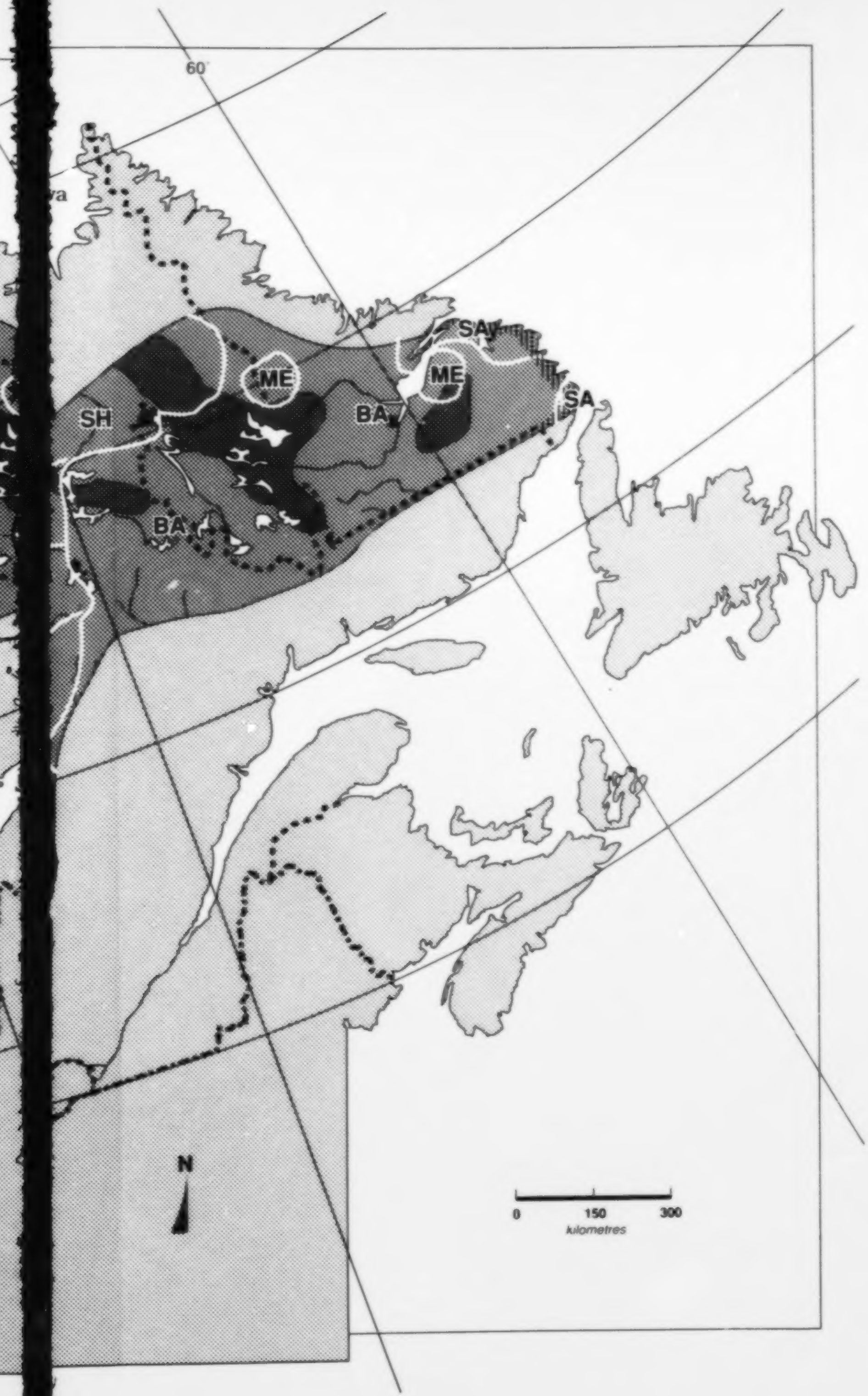
The environmental setting identifies the dominant controls on wetland development as related to physiography and climate. A brief summary of dominant vegetation, soils and wildlife associated with each wetland region is also provided. The physiographic descriptions identify specific landform-relief templates which affect wetland distribution and types in each wetland region. This information is drawn largely from the maps and data sources identified in Chapter 2.

The wetland characteristics subsection provides an overview of the wetland types, their distribution, surface expression, selected soil characteristics, active layer thickness (where appropriate) and surface water cover. A table summarizing this information has been prepared for each major wetland region in the Northern Wetlands Study area. The tables are subdivided on the basis of the major physiographic templates identified in the environmental setting subsection. The information provided represents the most characteristic con-

---

[1] These figures are based on summing the provincial totals calculated by Tarnocai (1984) with one-half the total for Newfoundland-Labrador attributed to Labrador.


60°
100
90°
80°
70°
60°
Ungava Bay
Hudson Bay
SL
SH
SH
SH
55°
BHc
SL
James Bay
SL
BA
BHh
BHh
BMc
50°
PC
BMh
BL
BL
BL
Lake Superior
Lake Huron
45°
N
Lake Ontario
Lake Michigan
Lake Erie



map 3.1.1

NORTHERN WETLANDS STUDY AREA

Wetland regions and percentage cover of wetlands

Wetland regions (defined by white borders)

SA	Atlantic Sub-arctic
SH	High Sub-arctic
SL	Low Sub-arctic
BHh	High Boreal humid
BHc	High Boreal continental
BMh	Mid Boreal humid
BMc	Mid Boreal continental
BL	Low Boreal
BA	Atlantic Boreal
PC	Prairie Continental
ME	Eastern Mountain

Percentage cover of wetlands

▥	0-5%
░	6-25%
▓	26-50%
■	51-75%
■	76%-100%

Source:
Wetland Regions & Wetland Distribution, 1:7.5 m
(National Wetlands Working Group, 1986)

Projection: polar stereographic

ditions for that portion of the wetland region as interpreted from the literature. Sources utilized to prepare each table are referenced.

The dominant wetland types occurring within each wetland region are described in some detail according to peat, permafrost, vegetation, hydrological function and overall appearance. Descriptions are based on examples from within the Northern Wetlands Study area as described in the literature. Information on depth to water table, peat depth and groundwater chemistry are provided from site specific studies, as available.

The toposequence subsection illustrates relationships among soil, wetland type and landform for selected wetlands of each region using conceptual diagrams.

Wetland type terminology follows the Canadian Wetland Classification System as utilized in *Wetlands of Canada* (National Wetlands Working Group 1988). This classification is based on vegetation physiognomy, hydrology and water chemistry. At the most general level there are five classes: fen, bog, swamp, marsh and shallow open water. Within the Canadian System, these classes are subdivided according to wetland form such as flat, domed, ribbed, etc. (Zoltai 1988). However, physiognomic subdivisions of the five major classes have also been employed in the literature. These include subclasses such as treed, open (non-treed), shrub-rich, graminoid (grass-rich), thicket, etc. as defined in the classification of Jeglum *et al.* (1974). Although the wetland form system of classification is used in this chapter, physiognomic subdivisions are identified to correspond to the literature.

The purpose of this document is to describe the wetlands and the resources which affect wetland development in the Northern Wetlands Study area. No attempt has been made to summarize the voluminous literature regarding the chemical or physical processes associated with wetland evolution. Excellent summaries of these processes are available in the following references: Moore and Bellamy (1974), Gore (1983) and Zoltai (1988).

3.2 SUB-ARCTIC WETLANDS

The Sub-arctic is transitional between the treeless Arctic and the forested Boreal (Zoltai *et al.* 1988a). It is similar to the area referred to as the Forest Tundra (Rowe 1972, Stanek 1973). The Sub-arctic is subdivided into 3 major wetland regions: the High Sub-arctic, the Low Sub-arctic and the Atlantic Sub-arctic (Map 3.1.1).

The Sub-arctic Ecoclimatic Region, defined by the Ecoregions Working Group (1989) on the basis of vegetation and climate, is comparable to the area encompassing the High and Low Sub-arctic wetland regions. Vegetationally, it ranges from the closed mixed forest of the Boreal to the open tundra of the Arctic. Black spruce woodlands are most characteristic of the Sub-arctic, becoming more stunted and open canopied toward the north. Climatically, the Sub-arctic is defined as having a mean annual temperature of -9.8°C, 51 days mean frost-free period and mean total annual precipitation of 266 mm (Ecoregions Working Group 1989). The Sub-arctic lies almost entirely within the discontinuous permafrost zone but overlaps into the continuous permafrost zone to the north (Brown 1967).

Sub-arctic Wetland Regions are characterized by intensely cold winters and short, cool summers with relatively low precipitation throughout the year (Zoltai 1988). Precipitation within the Sub-arctic generally increases from western Canada to eastern Canada resulting in more restricted permafrost development in the east. West of the study area, permafrost is present in all Sub-arctic peatlands. Within the study area it is sporadic, being most common as ice lenses in palsa and peat plateau bogs (Zoltai 1988). Ice-wedge polygons occur in deep peats north of the Nelson River in Manitoba (Stanek 1973).

Wetland development within the Sub-arctic Wetland Region of the study area is best expressed in the Hudson Bay Lowland of Manitoba, Ontario and Québec. Approximately 70 percent of this Lowland, home to the largest expanse of wetlands in Canada and the second most expansive in the world, lies within the Sub-arctic Wetland Region of the Northern Wetlands Study area. About 20 percent of the Lowland is in the High Sub-arctic, mostly along the coast of Hudson Bay, and about 50 percent is in the Low Sub-arctic. The remainder lies in the High and Mid Boreal Wetland Regions.

Bog and fen wetlands dominate the organic landscape of the Lowland, however, significant areas of peat swamps and mineral soil wetlands such as riparian (river edge) swamps, freshwater marshes and salt marshes are present. Areal coverage of vegetation and terrain patterns in the Ontario portion of the Hudson Bay Lowland north of 52°N latitude have been determined by Cowell *et al.* (1983) from the vegetation map prepared by Bates and Simkin (1969). From these calculations an estimate of major wetland types can be derived: bogs plus nutrient-poor swamp, 48 percent; fen, 18 percent; swamp, 14 percent; marsh (freshwater and salt marshes), 3 percent. The remainder consists of upland (8 percent) and open water (9 percent).

Riley (1988) calculated the areal coverage of the major wetland types for the Ontario portion of the Hudson Bay Lowland based on occurrence along a north-south transect (also Riley 1982, pp 550 to 552). Data were obtained from an intensive sampling program carried out during the late 1970's. Riley (1988) calculated the total area of wetlands (not including upland areas) of the Ontario portion of the Hudson Bay Lowland to be 22.1 million ha with the following composition: bog 36.2 percent (8.0 million ha); palsa and peat plateau bog, 21.6 percent (4.77 million ha); fen, 24 percent (5.3 million ha); swamp, 12.7 percent (2.8 million ha); and marsh (freshwater and salt marsh), 5.5 percent (1.23 million ha). No estimate for upland areas was provided, however, allowing for an upland cover of about 10 percent, the two sets of estimates are remarkably similar.

Widespread wetlands also occur in the Low Sub-arctic of Manitoba on glacial Lake Agassiz sediments. The Atlantic Sub-arctic Wetland Region, located along the Atlantic coasts of Labrador and Québec, is predominately upland with wetlands occupying less than 26 percent of its area.

3.2.1 HIGH SUB-ARCTIC WETLAND REGION

3.2.1.1 ENVIRONMENTAL SETTING

Physiography

The High Sub-arctic Wetland Region consists of two distinct physiographic templates within the Northern Wetlands Study area. In the northwest, it occupies a narrow coastal strip along the southwest shore of Hudson Bay almost entirely within the Hudson Bay Lowland Physiographic Division (Section 2.5.2). The largest extent of the High Sub-arctic in the study area lies to the east of Hudson Bay occupying large portions of the Larch Plateau, Labrador Hills and Whale Lowland Physiographic Divisions of north-central Québec. The Churchill research site for the Northern Wetlands Study is located near the coast of Hudson Bay in the Lowland portion of the High Sub-arctic.

During the most recent glacial period, the area around Hudson Bay experienced severe downwarping from the weight of the ice. The southern and western shores of Hudson Bay are very flat and, hence, a small increment of isostatic uplift produces a relatively rapid retreat of the shoreline. The result is the continual addition of 'new' land to the coastal plain.

In the western portion of this coastal plain are numerous large parallel and well drained beach ridges associated with poorly drained inter-ridge swales (Wickware and Rubec 1988). The beach ridges are sparsely vegetated near the coast and characteristically deflated with the finer sand particles removed. Further inland, the ridges and swales become increasingly paludified. Only the highest and largest of the inland beach ridges remain recognizable. Toward the east, ridges become less common and less well developed. Extensive muddy tidal flats, often with large boulders which are pushed onto the shore by ice in Hudson Bay, occur throughout this portion of the High Sub-arctic Wetland Region.

In Québec, the High Sub-arctic Wetland Region is dominated by the Larch Plateau Physiographic Division. This is an undulating plain with elevations in the range of 150 to 450 m. Drainage is primarily toward Ungava Bay except for the extreme western portion along Hudson Bay. Bedrock is primarily granitic and is widely exposed with only thin localized morainal deposits (Gilbert *et al.* 1985). In the southern portions, along Hudson Bay, fine sediments are found in valleys (Gilbert *et al.* 1985). These include marine clays deposited during higher postglacial marine stages of Hudson Bay (referred to as the Tyrrell Sea). The Whale Lowland Physiographic Division forms the eastern extremity of the High Sub-arctic Wetland Region. This Lowland is composed of both granitic and sedimentary bedrock generally covered by thick glacial deposits (Gilbert *et al.* 1985). These deposits are primarily morainal including drumlin features and ribbed moraines. The Whale Lowland is characterized by scattered bedrock knobs rising above the glacial deposits and reaching about 250 m elevation in its northern portion.

Climate

The High Sub-arctic Wetland Region occurs in a harsh climatic region where the winters are very cold and summers are short and cool. The regional climate is affected by seasonal changes in the position of the Arctic Front. In winter, its more southerly location allows dominance of cold arctic air and its movement northward allows incursions of temperate moist air in the summer. Sub-arctic and tundra vegetation develop where Arctic air masses dominate for more than 10 months (Bryson and Hare 1974). In this region, there is a significant contrast between coastal and inland sites due to the influence of Hudson and James Bays (Rouse and Bello 1985, Lafleur and Rouse 1988). Coastal sites experience stronger winds, more cloudy conditions and modification of temperature. Summary statistics of climatic elements are presented in Table 3.2.1.

TABLE 3.2.1

High Sub-arctic Wetland Region climate statistics.*

CLIMATE ELEMENT		Mean	Range
Bright Sunshine (hours)**		1608	1497 to 1828
Precipitation (mm)	— Annual	549	402 to 769
Snowfall (cm)	— Annual	241	130 to 387
Temperature (°C)	— Annual	-5.4	-4.3 to -7.2
	— January	-25.2	-22.5 to -28.5
	— July	12.2	10.5 to 15.6
Growing Degree-days (°C)		645	554 to 952
Growing Season (days)		106	85 to 127
Freeze-free days (days)		117	109 to 132

* Statistics compiled for the period 1951 to 1980 from 6 stations within the High Sub-arctic region of the Northern Wetlands Study area.

** Based on 3 stations.

Bright sunshine declines from west to east. At Kuujjuarpik, for example, cloudiness and fog are high in spring and fall when there is a large contrast between air and water temperatures. The least cloudiness occurs in the winter, when Hudson Bay is frozen.

Total annual precipitation increases from west to east; Churchill receives 402 mm precipitation annually while Schefferville receives 769 mm. The west is influenced more frequently by cold arctic air which contains little moisture. Hudson Bay may provide a significant source of atmospheric moisture for the east side of the Bay. Orographic influence is limited to the rocky headlands along the east coast of Hudson Bay (near Kuujjuarapik).

The lands adjacent to Hudson and James Bays are cold as compared to other areas at the same latitude. They contain the most southerly extent of Sub-arctic vegetation and permafrost. Hudson Bay is a large expanse of cold water which delays spring warming and modifies summer temperatures so that they are cooler than inland. In winter, the large frozen ice surface allows cold arctic air to sweep from the northwest without modification. Annual mean temperatures and mean January temperatures increase from west to east.

Vegetation, Soils, Permafrost and Wildlife

Trees, where present, are characteristically stunted and very open grown. Upland sites are dominated by black spruce (*Picea mariana*) with occasional white spruce (*Picea glauca*) and a ground cover consisting of dwarf birch (*Betula glandulosa*), willows (*Salix* spp.), Labrador tea (*Ledum groenlandicum*), cottongrass (*Eriophorum angustifolium*), bog cranberry and crowberry (*Vaccinium* spp.), various mosses especially feather mosses (e.g. *Pleurozium schreberi*) and lichens (*Cladonia* spp.) (Ecoregions Working Group 1989). Large areas of stunted spruce with abundant lichen cover, referred to as 'lichen-woodlands', are common in the High Sub-arctic. Toward the north, the lichen-woodlands give way to tundra vegetation (Section 2.8). Wetter sites within this region are dominated by mounds or tussocks of sedges (*Carex* spp.) and cottongrass in association with sphagnum mosses (Ecoregions Working Group 1989).

Upland mineral soils dominate the eastern portion of this wetland region in Québec. These soils are dominantly Regosols and poorly developed Dystric Brunisols on well-drained, coarse textured materials (Gilbert *et al.* 1985) and Brunisolic Cryosols on moist to imperfectly drained upland soils. Soils in wetlands are primarily shallow to moderately deep Fibric and Mesic Organic Cryosols (Section 2.6). Orthic Gleysols are common in the salt marshes and freshwater marshes along the southwestern coast of Hudson Bay (Protz 1982a). Interior beach ridges which have not been paludified commonly have Humo-Ferric Podzols (Protz 1982b).

The High Sub-arctic Wetland Region lies within the continuous permafrost zone in Manitoba and Ontario (Section 2.6). Brown (1978) reports permafrost thickness at Churchill, Manitoba as being 60 m. Ground temperatures are -2.5°C and -1.7°C at depths of 7.5 and 16.5 m, respectively (Brown 1967). Ground temperatures in bedrock (sandstone) near the airport at Churchill were found to have a great variation throughout the year (the greatest of four northern stations reported) and near-surface temperatures fluctuated rapidly during the June to September period (Etkin *et al.* 1988). In Québec, the High Sub-arctic Wetland Region occupies the southern half of the area of widespread discontinuous permafrost (Map 2.6.3).

Wildlife common to the High Sub-arctic Wetland Region within the Northern Wetlands Study area include caribou (Québec and northern Manitoba), moose, black bear, polar bear (Hudson Bay coast in Ontario and Manitoba), wolf, coyote, beaver, snowshoe hare, muskrat, red fox, spruce grouse, raven and osprey (Ecoregions Working Group 1989). At least one major caribou herd utilizes the area within Québec for its winter range.

3.2.1.2 WETLAND CHARACTERISTICS

Table 3.2.2 summarizes wetland characteristics for the two major physiographic areas of the High Sub-arctic Wetland Region; the Hudson Bay Lowland coastal zone (southwestern shore of Hudson Bay) and the Shield area of north central Québec.

Wetlands of the Canadian Shield in the High Sub-arctic of Québec are primarily palsa bogs surrounded by horizontal fens in shallow rock basins (Zarnovican and Belair 1979). The bogs are treeless with hummocky surfaces. Organic accumulation is the lowest, on average, for the study area (Tarnocai 1984). Soils are primarily Fibric Organic Cryosols on the palsa bogs and peaty phase Gleysols and Terric Fibrisols/Mesisols in the fens. The soil types without permafrost development reflect the shallow peat accumulation. Palsa bogs are composed of fibric sphagnum moss peats and the fen peats are fibric sphagnum peat at the surface overlying mesic sedge peats. The mean annual soil temperature is higher in this portion of the High Sub-arctic than at Churchill in the western portion, even though Churchill lies much further south. This reflects the cooling effect of Hudson Bay which accounts for the southerly extension of the continuous permafrost zone southwest of the Bay. Surface water cover averages between 10 and 20 percent.

The Hudson Bay Lowland has the highest concentration and the greatest variety of wetlands in the study area. The wetlands are youthful. They are less than 4000 to 5000 years old at their furthest point inland due to recent emergence of the coast from the sea (Protz *et al.* 1984 and 1988). For example, peat accumulation in freshwater marshes of the York Factory area is estimated to have commenced about 600 years following emergence (Tarnocai 1982). The wide variety of wetland types in this portion of the High Sub-arctic Wetland Region is the product of isostatic uplift causing coastal emergence which results in a strong time gradient and a range of minerotrophic conditions.

Brackish conditions occur at the coast due to the influence of salt and brackish waters of Hudson Bay. A range of minerotrophic wetlands and peatlands occur inland of the coast and ombrotrophic peatlands occur further inland where the base-rich substrate has been isolated from the living community by peat accumulation and permafrost.

Riley (1982) describes the High Sub-arctic Wetland Region in the Lowland as strongly influenced by permafrost particularly as shown by the development of permafrost peatlands such as palsa bogs and plateau bogs. Freshwater marshes parallel the coast and thicket (shrub) swamps are common along drainageways. Salt and brackish marshes are not as widespread as along the James Bay coast (Low Sub-arctic) due to a steeper shoreline and corresponding narrower tidal zone along Hudson Bay (Riley 1982). Freshwater marshes give way to broad horizontal fens which in turn are replaced by the permafrost bog landforms. Ribbed fens are common as drainageways between beach ridges and plateau bogs. Uplands including beach ridges and river levées occupy about 15 percent of the area, plateau and palsa bogs 35 percent, flat bog 5 percent, horizontal and ribbed fens 35 percent and marshes and swamps about 10 percent (Riley 1982).

The depth of peat ranges from nil at the coast to a maximum of approximately 1.5 m within the High Sub-arctic Wetland Region (Sims *et al.* 1987). Peats are moderately decomposed (mesic) reflecting their origin as grasses and sedges in freshwater marshes and coastal fens. Fibric material forms the uppermost layer in the bog types but most of the peat material is mesic in decomposition. Soil types include wide areas of organic soils (mostly thin Terric Mesisols in fens), cryosols (Fibric Organic Cryosols in palsa and plateau bogs) and mineral wetland soils (mostly peaty phase Rego Gleysols in marshes and thicket swamps). The soil climates are classed as Sub-arctic and are saturated for long periods. Within the High Sub-arctic Wetland Region of the Northern Wetlands Study area, permafrost is restricted primarily to palsa and plateau bogs where the active layer reaches only 30 to 50 cm. Inland fens serve as drainage-ways between beach ridges and plateau bogs and water flow is sufficient to prevent permafrost development. The surface of the wetlands are flat to hummocky. Hummocky conditions occur mostly in palsa and plateau bogs due to the presence of permafrost. The overall gradient toward Hudson Bay is extremely shallow. Beach ridges and large plateau bogs impede drainage.

Tarnocai (1972) provides a detailed description of a Mesic Organic Cryosol from a palsa bog in the York Factory area ('Silcox Soil'); Tarnocai (1982) and Ritchie (1960) describe wetland types, vegetation and soils in the vicinity of York Factory—Hayes River, Manitoba; and Brown-Beckel (1957) reports detailed measurements of the active layer in several upland and wetland sites at Churchill, Manitoba. More recent ground temperature measurements from Churchill have been reported by Young and Judge (1985).

3.2.1.3 WETLAND TYPES

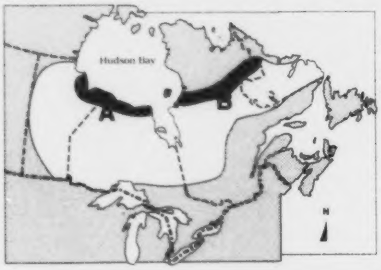
The wetland types which are most characteristic of the High Sub-arctic within the Northern Wetlands Study area are palsa bog, peat plateau bog, veneer bog, horizontal fen, northern ribbed fen, freshwater marsh and salt marsh. Marshes occur along the coast of Hudson Bay in Ontario and Manitoba. Descriptions of

TABLE 3.2.2

Wetland characteristics of the High Sub-arctic Wetland Region.

	HUDSON BAY LOWLAND (A)	CANADIAN SHIELD (B)
WETLAND TYPES	Palsa Bog, Polgonal Peat Plateau Bog, Plateau Bog, Veneer Bog, Horizontal Fen, Northern Ribbed Fen, Freshwater Marsh, Salt Marsh	Palsa Bog, Horizontal Fen
WETLAND DISTRIBUTION (%)	85	6 to 25
MORPHOLOGY/SLOPE	flat, hummocky/level	hummocky/level-confined
DEPTH OF PEAT (cm)	0 to 150	<100
DECOMPOSITION	60 to 75% mesic	fibric
WETLAND SOILS	Orthic Gleysol Peaty Phase Rego Gleysol Terric Mesisol Fibric Organic Cryosol	Peaty Phase Rego Gleysol Terric Fibrisol Fibric Organic Cryosol
SOIL CLIMATE (Temp/Moisture)	Subarctic/Peraquic	Subarctic/Humid
MEAN ANNUAL GROUND TEMPERATURE (°C)	-1.6 (Churchill)	-0.7 to 1.4
ACTIVE LAYER THICKNESS (cm)	30 to 50	30 to 50
SURFACE WATER COVER (%)	-	10 to 20

SOURCES:
Clayton *et al.* 1977; Cowell *et al.* 1983; Manitoba-Canada Soil Survey 1986; National Wetlands Working Group 1986; Riley 1982. Ritchie 1959, 1960; Sims *et al.* Tarnocai 1987; Tarnocai 1972; Young and Judge 1985; Zarnovican and Belair 1979.



veneer bog and horizontal fen types are provided in Section 3.2.2.3 (Low Sub-arctic). Data on peat depth, groundwater pH and depth to the water table for marsh, swamp, fen and bog types in the High Sub-arctic of Ontario are provided in Table 3.2.3.

Marsh

Marshes are highly minerotrophic wetlands. In the High and Low Sub-arctic, they are most common along the coast of Hudson and James Bays. Salt and brackish marshes occur in the mid to upper portion of the zone of tidal inundation and freshwater marshes occur immediately inland, above tidal influence.

Based primarily on vegetation, Glooschenko *et al.* (1988) classified salt marshes north of the Attawapiskat River along James and Hudson Bays as Sub-arctic. These were not differentiated on the basis of low or high Sub-arctic. Salt marshes south of the Attawapiskat River on James Bay were classified as boreal.

In the Sub-arctic marshes, the dominant vegetation species of relatively high salinity tidal flats is *Puccinellia phryganodes* and for lower salinity flats is *Hippuris tetraphylla*. The higher portions of the flats are characterized by the sedge *Carex subspathacea* and by herbs such as *Potentilla egedii* (Glooschenko *et al.* 1988).

There is virtually no organic matter accumulation at the surface of these marshes. This is a result of tidal action which either washes the material away or buries it under silt layers. However, abundant organic material occurs beneath the mineral surface as a result of burial by sediments or in the form of dense root mass (Martini and Protz 1978, Martini *et al.* 1979 and 1980, Martini 1981, Clarke *et al.* 1982). The soil zone immediately beneath the surface of these marshes is anaerobic with very strong reducing conditions. This is expressed by extremely dark colours within 20 cm of the surface (Protz 1982a, Wickware & Associates Inc. 1990). The water table fluctuates with tidal cycles but generally lies near the mineral surface (Table 3.2.3).

Freshwater marshes occur above the zone of tidal inundation and are transitional between salt marsh and fen (Sims *et al.* 1987, Wickware & Associates Inc. 1990). Dominant vegetation includes sedges (*Carex aquatilis*), willows (*Salix brachycarpa*), rushes (*Juncus balticus*), sweet coltsfoot (*Petasites sagittatus*) and reed grass (*Calamagrostis stricta*). Cattails (*Typha latifolia*) are also common in Low Sub-arctic freshwater marshes. Freshwater marshes are characterized by the accumulation of non-decomposed to slightly decomposed peat (generally less than 25 cm thick), a water table at or slightly above the surface and strongly reduced gleyed mineral soils immediately beneath the peat (Protz 1982b, Wickware & Associates Inc. 1990). The mineral layer has abundant organic material in the upper portions which is likely a remnant of the former salt marsh vegetation.

Salt marshes have a relatively low primary productivity relative to other marshes (Glooschenko *et al.* 1988). Soils and groundwaters are nutrient-rich with pH greater than 7.0 and concentrations of calcium, magnesium and sodium the highest of all wetlands.

TABLE 3.2.3

Means (standard deviations) for peat depth, depth to water table and groundwater pH for marsh, swamp, fen and bog types in the High Sub-arctic portion of the Hudson Bay Lowland (Ontario). Graminoid fens and low shrub fens correspond primarily to horizontal fens whereas treed fens represent the string phase of ribbed fens. Bog types are primarily plateau and palsa bogs.

WETLAND	NUMBER OF SAMPLES	DEPTH TO WATER LEVEL (cm)	PEAT DEPTH (cm)*	GROUNDWATER (pH)
Brackish Marsh	5	0.4 (3.1)	2	7.2 (0.8)
Freshwater Marsh	5	2.3 (4.6)	5	6.9 (0.9)
Thicket Swamp	3	1.7 (12.6)	35	6.9 (0.6)
Graminoid Fen	38	0.9 (5.9)	70	6.4 (0.6)
Low Shrub Fen	4	15.2 (19.2)	45	6.9 (0.5)
Treed Fen	9	9.3 (5.7)	75	6.7 (0.7)
Low Shrub Bog	6	17.0 (8.5)	140	4.4 (0.2)

SOURCE: Sims *et al.* 1987

* Approximate

Northern Ribbed Fens

Northern ribbed fens are minerotrophic wetlands "...characterized by low, narrow peat ridges that cut across the fens at right angles to the direction of water movement" (Zoltai *et al.* 1988a). The ridges are also referred to as strings and are spaced from 5 to several tens of metres apart, generally becoming more closely spaced as slope increases. Northern ribbed fens develop where the groundwater seepage zone is somewhat restricted compared to horizontal fens. Ribbed fens are common in the High Sub-arctic of the Hudson Bay Lowland and throughout the Low Sub-arctic and the High Boreal Wetland Regions. The main difference between Boreal and Sub-arctic ribbed fens is the presence of permafrost in the ridges in the Sub-arctic (Zoltai *et al.* 1988a).

The ridges (referred to as 'strings') are formed of denser peat than the intervening swales ('flarks') and are generally 10 to 30 cm high (Zoltai *et al.* 1988a). The strings act as dams to the movement of water through the fen. They are also drier than the main part of the fen and provide greater insulation which permits the preservation of seasonal frost until late in the summer. This may eventually lead to the development of permafrost (Zoltai *et al.* 1988a). The establishment of permafrost leads to further elevation of the string above the surrounding pools and may eventually result in the formation of peat plateau bogs on the ridges.

Zoltai *et al.* (1988a) describe the vegetation of northern ribbed fens as dominated by *Carex* spp. and *Eriophorum vaginatum* with mosses such as *Drepanocladus* spp., *Scorpidium* spp., *Campylium* spp., and *Pohlia* spp. in the flarks with the strings dominated by shrubs such as *Ledum groendlandicum, Betula glandulosa* and *Chamaedaphne calyculata* and sphagnum mosses (*S. fuscum* and *S. magellanicum*). Ridges that are well elevated by permafrost have vegetation resembling peat plateau bogs with more shrubs and lichen and the growth of scattered black spruce (*Picea mariana*).

Low shrub fens and treed fens in the Ontario portion of the High Sub-arctic are physiognomic types which characteristically form the string phase in ribbed fens. Common vegetation of the low shrub fens in this area includes shrubs such as *Salix pedicellaris, S. arctophila,* and *Betula glandulosa* along with *Scorpidium scorpioides* and *Aulacomnium palustre*. Treed fens are characterized by tamarack (*Larix laricina*), *Carex aquatilis, Tomenthypnum nitens* and *Sphagnum nemoreum* (Sims *et al.* 1987). The peat depths in these fens averaged between 45 and 75 cm (Table 3.2.3).

Peat Plateau Bogs

Peat plateau bogs are ombrotrophic wetlands defined by Zoltai *et al.* (1988a) as "...perennially frozen peatlands elevated about 1 m above the water table of the associated wetlands". Associated wetlands are typically horizontal and ribbed fens without permafrost. Peat plateau bogs are flat with only minor surface irregularities. They have typical bog vegetation with scattered stunted black spruce (*Picea mariana*) and abundant moss (*Sphagnum* spp.) and lichen cover.

Peat plateau bogs cover large areas and individual bogs can be several square kilometres in extent (Zoltai *et al.* 1988a). They are most common in the High Sub-arctic and more northerly portions of the Low Sub-arctic. These bogs become less frequent toward the south and are virtually absent south of the Attawapiskat River. Here they give way to the flat bogs described in Section 3.2.2.

The surface of these bogs tend to dry out during the summer period as the active layer thaws and drains into the surrounding fen. In late summer, there may be no free-standing water table and, as a result, plateau bogs become very susceptible to fires. The surface peats of these bogs are commonly composed of weakly to non-decomposed sphagnum moss. Moderately decomposed sedge peats which accumulated in fens prior to the development of the bog plateau usually underlay the sphagnum peat within the frozen core and extending down to the mineral soil boundary.

Typical vegetation of these bogs in the Ontario portion of the High Sub-arctic includes black spruce, Labrador tea (*Ledum groenlandicum*), swamp laurel (*Kalmia polifolia*), *Sphagnum fuscum, S. nemoreum, Pleurozium schreberi* and *Cladina* spp. lichens. The low shrub bog phase has similar vegetation (without black spruce) as well as *Ledum decumbens, Empetrum nigrum* (crowberry), *Oxycoccus microcarpus* and *S. magellanicum* (Sims *et al.* 1987). Peat depths average from 80 to 140 cm (Table 3.2.3) and are the deepest of all types described within this wetland region by Sims *et al.* (1987).

Palsa Bogs

Palsa bogs are ombrotrophic permafrost-cored peatlands which are mounded 1 to 7 m above the surrounding wetland and have a diameter of less than 100 m (Zoltai *et al.* 1988a). They appear as islands in wet unfrozen ponds or fens and occur either singly or in groups. The vegetation is similar to the peat plateau bogs with lichens dominating the surface, up to 20 percent dwarf shrubs (*Ledum decumbens* and *Rubus chamaemorus*) and an open tree cover of stunted *Picea mariana* (Zoltai *et al.* 1988a).

The active layer of palsas is generally within the range of 30 to 50 cm mostly in weakly to undecomposed sphagnum moss peats. The sphagnum peat is underlain by fen peats including moderately decomposed sedge peats and brown moss peat. Peat thickness in Sub-arctic palsa bogs averages 267 cm, ranging from 140 to 442 cm as reported by Zoltai and Tarnocai (1975). Degradation of the permafrost core occurs when it becomes exposed due to cracking of the surface or due to melting from the edges inward (Zoltai *et al.* 1988a).

The palsas on shallow rock basins of the High Sub-arctic in Québec are non-wooded with lichens (*Cladonia* spp. and *Cetraria nivalis*), mosses (*Polytrichum juniperinum*) and dwarf birch (*Betula glandulosa*). Poor fen areas between the palsas have up to 200 cm of peat and are characterized by sphagnum moss (*Sphagnum riparium*), sedges (*Carex paupercula*), grasses (*Calamagrostis canadensis*) and herbs (*Epilobium palustre*) (Zarnovican and Belair 1979).

3.2.1.4 HIGH SUB-ARCTIC TOPOSEQUENCE

Figure 3.2.1 illustrates the relationship among soils, landform and wetland types for the High Sub-arctic Wetland Region. It is based on a conceptual model representing the south shore of Hudson Bay in the vicinity of Peawanuck, Ontario (formerly Winisk). Wetland sequences range from a narrow zone of salt marsh at the coast through freshwater marshes, where peat first begins to accumulate, to fen and bog. Horizontal fens are generally best expressed nearest the coast but are not as extensive as those of the James Bay coast in the Low Sub-arctic Wetland Region. Small 'incipient' or 'brown moss' palsas (Jeglum and Cowell 1982) form in fens nearest the coast in areas of least water movement. Permafrost in these small palsas generally does not extend into the underlying mineral soil. Further inland are true palsa bogs and plateau bogs with permafrost extending into the underlying mineral soil. Permafrost may also be found in the mineral soils of beach ridges which are undergoing paludification and have sufficient peat to insulate the underlying podzolic soil (Cowell *et al.* 1982). Fens in this area serve as drainageways between permafrost landforms and beach ridges and may be either northern ribbed fens or channel fens (described in Section 3.2.2).

The satellite image of the Churchill, Manitoba area (Image 3.2.1) illustrates a relatively rapid transition from coastal wetland ecosystems to mature bog plateau complexes in this portion of the High Sub-arctic. The smooth-patterned, medium-toned areas along the coast on either side of the Churchill River are large freshwater marshes grading inland to horizontal fens. The lighter-toned area with dense lake formation represents extensive areas of palsa bogs and plateau bogs. Light tones are indicative of abundant lichen growth on the dry surfaces of these permafrost peatlands. Long parallel beach ridges are most visible on the right of the image. These extend inland and a major raised complex trends across the image in the lower left. The large lakes in the right centre of the image are aligned in a linear pattern. These lakes occur in the swales between ridges as a result of the ridges impeding surface drainage.

3.2.2 LOW SUB-ARCTIC WETLAND REGION

3.2.2.1 ENVIRONMENTAL SETTING

Physiography

The Low Sub-arctic Wetland Region stretches across the map area in a broad arc from the extreme northwest in Manitoba, through the Hudson Bay Lowland and into Québec southeast of Hudson Bay (Map 3.1.1). The region spans a range of terrain conditions including 4 physiographic Divisions: the Kazan Upland, the Hudson Bay Lowland, the Larch Plateau, and the Lake Plateau (Map 2.5.2).

The northwestern portion of the Kazan Upland, in northern Manitoba, and the Larch and Lake Plateaux, in Québec, consist of a wide expanse of typical Shield terrain (Bostock 1979). It is characterized by rolling bedrock hills with numerous lakes and confined basin wetlands. Local relief is usually less than 75 to 100 m. Elevations range up to a maximum of about 400 m in Manitoba and 1,000 m in the most easterly portion of the Low Sub-arctic Region in Québec. The uplands drain gradually toward Hudson and James Bays. The bedrock geology is primarily crystalline granitic rocks, hence, the geological strata in these areas are dominated by acid-type rocks and minerals. Surficial materials are primarily low-base coarse sands derived from shallow ground moraine deposits.

In the south and southeast of the Kazan Upland, the surficial material consists mostly of fine-grained glaciolacustrine sediments of glacial Lake Agassiz. As a result, this portion of the Low Sub-arctic Wetland Region is characterized by widespread to continuous wetlands. These sediments are rich in bases and would provide nutrients for the associated wetland deposits depending on local hydrologic and topographic controls.

FIGURE 3.2.1

Schematic cross section through the High Sub-arctic Wetland Region representing the Hudson Bay Lowland portion near Peawanuck (formerly Winisk), Ontario (modified from Wickware *et al.* 1980).

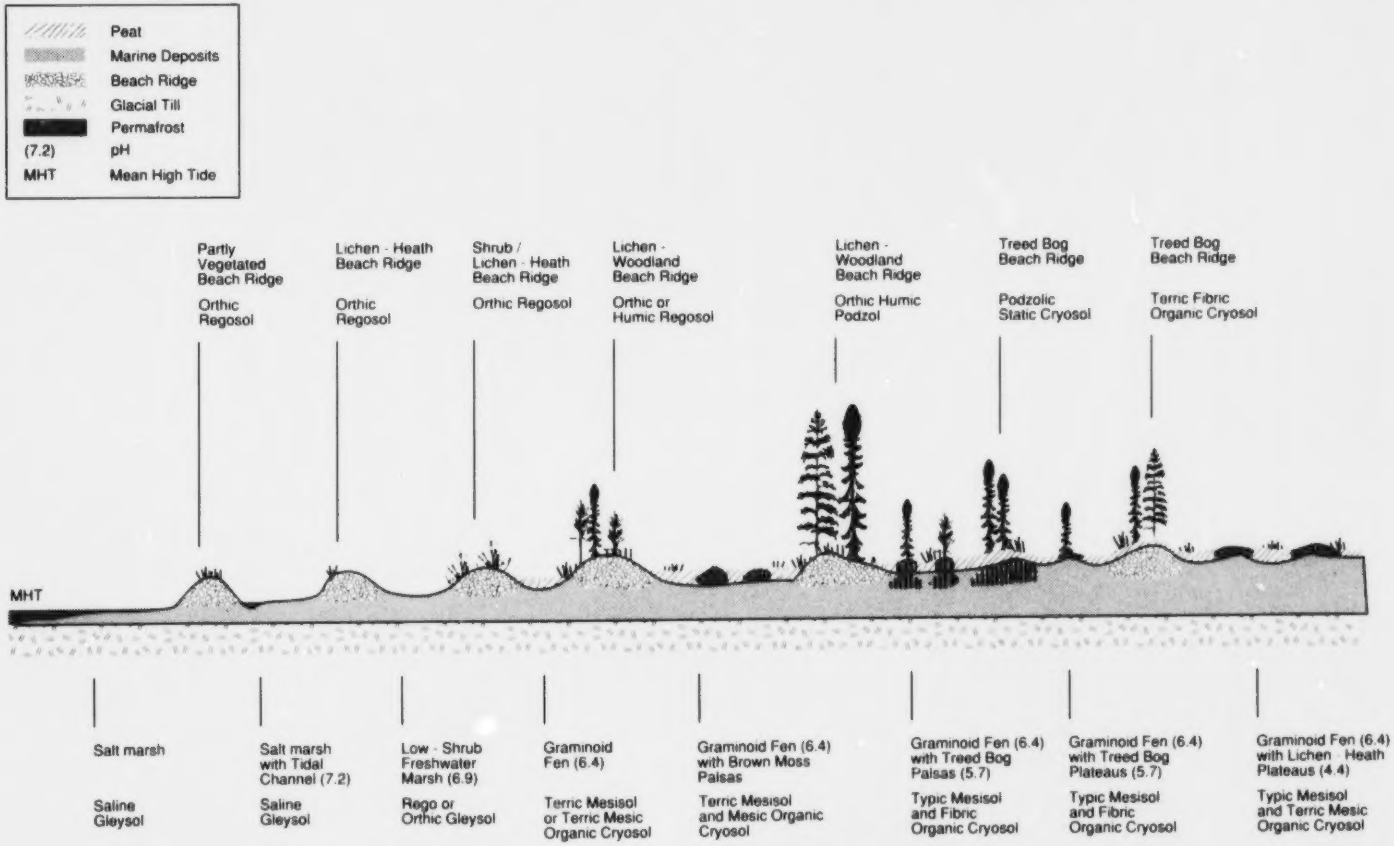
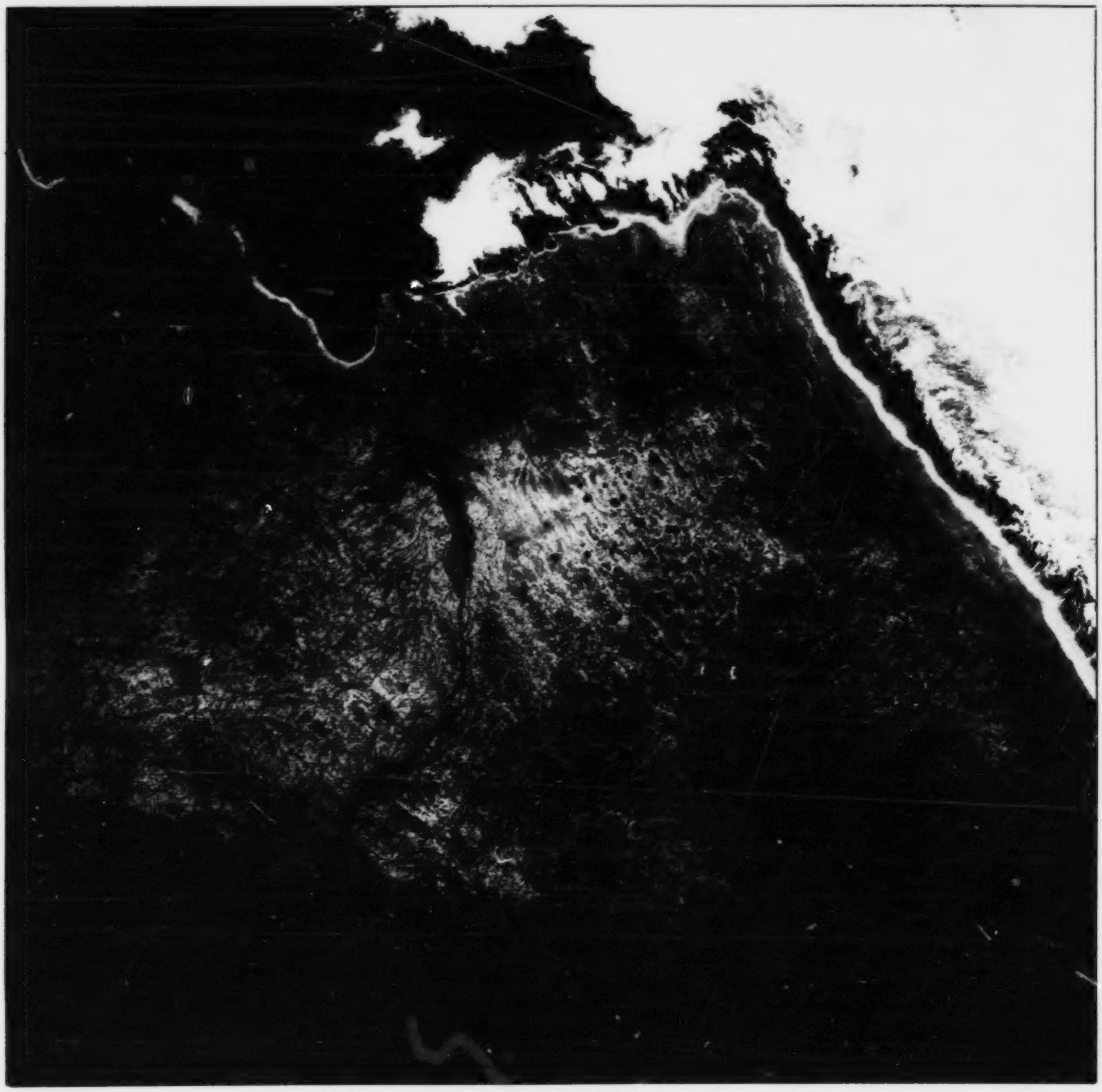

Peat
Marine Deposits
Beach Ridge
Glacial Till
Permafrost
(7.2) pH
MHT Mean High Tide
Partly Vegetated Beach Ridge
Orthic Regosol
Lichen - Heath Beach Ridge
Orthic Regosol
Shrub / Lichen - Heath Beach Ridge
Orthic Regosol
Lichen - Woodland Beach Ridge
Orthic or Humic Regosol
Lichen - Woodland Beach Ridge
Orthic Humic Podzol
Treed Bog Beach Ridge
Podzolic Static Cryosol
Treed Bog Beach Ridge
Terric Fibric Organic Cryosol
MHT
Salt marsh
Saline Gleysol
Salt marsh with Tidal Channel (7.2)
Saline Gleysol
Low - Shrub Freshwater Marsh (6.9)
Rego or Orthic Gleysol
Graminoid Fen (6.4)
Terric Mesisol or Terric Mesic Organic Cryosol
Graminoid Fen (6.4) with Brown Moss Palsas
Terric Mesisol and Mesic Organic Cryosol
Graminoid Fen (6.4) with Treed Bog Palsas (5.7)
Typic Mesisol and Fibric Organic Cryosol
Graminoid Fen (6.4) with Treed Bog Plateaus (5.7)
Typic Mesisol and Fibric Organic Cryosol
Graminoid Fen (6.4) with Lichen - Heath Plateaus (4.4)
Typic Mesisol and Terric Mesic Organic Cryosol

IMAGE 3.2.1

Landsat multispectral image (bands 4, 5 and 7) of the High Sub-arctic at Churchill Manitoba. The townsite of Churchill is located immediately east of the Churchill River (centre of image) at its outlet to Hudson Bay. The image was recorded on October 14, 1975 at a scale of 1:1 million.



The Hudson Bay Lowland Physiographic Region comprises almost half of the Low Sub-arctic Wetland Region in the Northern Wetlands Study area. The surface gradient of the Lowland is less than 1.0 m/km over a vast area, resulting in regionally high water tables and ideal conditions for unconfined peatland development.

Bedrock and surficial deposits of this region consist of base-rich materials. Bedrock is predominately Paleozoic limestone and dolomite (greater than 55 percent of the total thickness of the sedimentary strata) and outcrops occur along several of the major rivers in the Lowland. Glacial material consists primarily of carbonate-rich tills derived from the bedrock. Fine-grained marine sediments were deposited throughout the Lowland following and contemporaneous with deglaciation. The abundance of base-rich material in all sediments of the Lowland permits the development of minerotrophic wetlands which contributes to the great diversity of wetland types in this area.

Climate

Climatic statistics are summarized in Table 3.2.4. The Low Sub-arctic Wetland Region has a higher mean annual temperature than the High Sub-arctic wetland region. Winters are still very cold (-24.3°C January average), however, the summer temperatures are warmer. There is a 2.9°C difference in July mean temperature between the Low and High Sub-arctic. Colder mean January temperatures occur in the western portion of the region (Gillam) than in the central (Moosonee, Fort Albany) and eastern (Eastmain) sections. July mean temperature is less variable spatially.

TABLE 3.2.4

Low Sub-arctic Wetland Region climate statistics*

CLIMATE ELEMENT	Mean	Range
Bright Sunshine (hours)**	1623	-
Precipitation (mm) — Annual	552	403 to 728
Snowfall (cm) — Annual	214	148 to 258
Temperature (°C) — Annual	-3.2	-1.1 to -5.4
— January	-24.3	-20.4 to -28.0
— July	15.1	13.7 to 16.0
Growing Degree-days (°C)	987	872 to 1127
Growing Season (days)	115	86 to 136
Freeze-free days (days)	132	113 to 148

* Statistics compiled for the period 1951 to 1980 from 7 stations within the Low Sub-arctic region of the Northern Wetlands Study area.

** Based on 2 stations.

The Low Sub-arctic region has a significantly higher mean growing degree-day accumulation than the High Sub-arctic. The more southerly location of the Low Sub-arctic and its more continental climate are reflected by higher July temperatures which affect growing degree-days. The largest growing degree-day and longest freeze-free season occurs in the southern James Bay region.

Annual precipitation is lowest in the west and highest in Québec. Hudson and James Bays are likely a significant source of atmospheric moisture for the eastern portion of this region during the ice-free season. Snowfall comprises 40 percent of the annual total precipitation.

Vegetation, Soils, Permafrost and Wildlife

Productive forests (i.e., trees greater than 6 m high having a crown cover greater than 25 percent) are confined to the southernmost portion of the Low Sub-arctic Wetland Region particularly along river valleys. Portions of the Northwestern and Northeastern Transition Forest Sections and the Hudson Bay Lowland Forest Section, as defined by Rowe (1972), occur in the Low Sub-arctic Wetland Region within the study area (Map 2.8.1). Upland sites are dominated by open stands of black spruce (*Picea mariana*) with understorey species such as dwarf birch (*Betula glandulosa*), Labrador tea (*Ledum groenlandicum*), ground lichens (*Cladonia* spp.) and mosses (Ecoregions Working Group 1989). Trees are larger and more densely grown than in the High Sub-arctic. In the most southerly portion of the Low Sub-arctic Region, west of James Bay, river levées and raised beach ridges support closed stands of balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*) and black spruce. These forests approach the quality and composition of Boreal upland forests.

Soils are predominately Dystric or Eutric Brunisols on upland sites and Cryosolic Organic Mesisols or Terric and Typic Mesisols on organic sites. Orthic Humic and Humo-Ferric Podzols are characteristic of the older raised beach ridges (Protz 1982b, Wickware & Associates Inc. 1990).

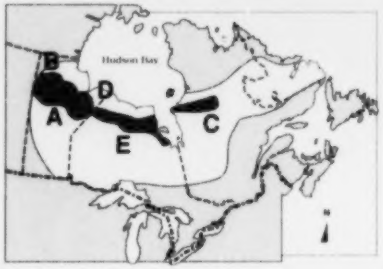
The Low Sub-arctic Region in the Northern Wetlands Study area occupies the most southerly portion of the discontinuous permafrost zone in Canada. In Manitoba, the region is primarily within the area of widespread permafrost whereas in Ontario and Québec it is mostly within the zone of scattered permafrost (Map 2.6.3). Permafrost is mainly restricted to peatlands where it is found under peat plateau bogs and palsa bogs (National Wetlands Working Group 1986). Uplands, swamps, marshes and fen peatlands are generally not affected by permafrost.

TABLE 3.2.5

Wetland characteristics of the Low Sub-arctic Wetland Region.

	CANADIAN SHIELD			HUDSON BAY LOWLAND	
	Glaciolacustrine	Ground Moraine/Bedrock			
	(A)	(B)	(C)	(D)	(E)
WETLAND TYPES	Veneer Bog	Peat Plateau, Palsa Bog	Veneer Bog, Palsa Bog	Peat Plateau Bog, Palsa Bog, Channel Fen, Horizontal Fen	Peat Plateau, Palsa Bog, Flat Bog, Northern Ribbed Fen, Conifer Swamp, Freshwater Marsh, Salt Marsh
WETLAND DISTRIBUTION (%)	26 to 75	6 to 25	6 to 25	85	85
MORPHOLOGY/SLOPE	hummocky/gently sloping to level	hummocky/level	hummocky/gently sloping to level	hummocky/level	hummocky/level
DEPTH OF PEAT (cm)	40 to 150	200 to 300 (x)	40 to 150	40 to 150	50 to 300 (interior) 0 to 200 (coastal)
DECOMPOSITION	fibric and mesic	fibric	mesic	mesic	40 to 75% mesic; remainder fibric
WETLAND SOILS	Mesic Organic Cryosol Terric Mesic Fibrisol	Fibric Organic Cryosol	Mesic Organic Cryosol Terric Mesisol	Mesic Organic Cryosol Cumulo Mesisol	Peaty Phase Rego Gleysol Orthic Gleysol Terric Fibric Mesisol Typic Mesisol Mesic Organic Cryosol
SOIL CLIMATE (Temp/Moisture)	Subartic/Subaquic	Subarctic/Humid	Cold Cryoboreal to Very Cold Subarctic/Perhumid	Subarctic/Peraquic	Subarctic to Cold Cryoboreal/Peraquic
MEAN ANNUAL GROUND TEMPERTURE (°C)	-	-	0.7	-	-
ACTIVE LAYER THICKNESS (cm)	40 to 60	40 to 80	50 to 80	40 to 60	40 to 70
SURFACE WATER COVER (%)	25 to 30	25	10 to 20	10	9

SOURCES:
Brown 1968; Cowell *et al.* 1982,1983; Cox 1978; Ecoregions Working Group 1989; Gilbert *et al.* 1985; Manitoba-Canada Soil Survey 1986; Mills *et al.* 1976a, 1976b; National Wetlands Working Group 1986; Tarnocai 1984; Young and Judge 1985; Zarnovican and Belair 1979



Wildlife species characteristic of the Low Sub-arctic Wetland Region include caribou (winter range), moose, black bear, red fox, arctic fox, snowshoe hare, spruce grouse, osprey, raven, whistling swan, lesser snow goose and Canada goose (Ecoregions Working Group 1989). The latter two species, along with numerous other shorebirds and ducks, breed in large numbers in the Hudson Bay Lowland which serves as nesting habitat as well as habitat for staging and feeding during spring and fall migrations (Martini *et al.* 1980).

3.2.2.2 WETLAND CHARACTERISTICS

Table 3.2.5 provides a summary of average or dominant conditions for wetlands of the Low Sub-arctic Wetland Region within the Northern Wetlands Study area. Wetland characteristics are identified according to physiographic setting and province.

The two major physiographic divisions are the Canadian Shield and the Hudson Bay Lowland. The Manitoba portion of the Canadian Shield has been further subdivided in order to distinguish the large glacial Lake Agassiz glaciolacustrine plain which is an important wetland area.

As in the case of the High Sub-arctic, wetland development reaches its greatest expression in the Hudson Bay Lowland. This is illustrated by the variety of wetland types, high wetland coverage and peat accumulation (Table 3.2.5). The Low Sub-arctic of the Lowland is dominated by plateau bogs, horizontal fen (graminoid, low shrub and treed), horizontal bog (low shrub and treed), swamp and coastal marshes (Riley 1982). From south to north, the relative coverage of these types changes; plateau bogs increase in dominance (from 15 percent to over 50 percent) at the expense of fen and bog types (Riley 1982). The area between the Winisk and Severn Rivers is dominated by a large area of thermokarst plateau bog which grades eastward into distinct plateau bogs intermixed with fen systems (horizontal and ribbed fen). Coastal and estuarine systems on eastern James Bay occupy a narrow zone which is proportionally smaller than in other portions of the Lowland (Riley 1982). A drier climatic regime in combination with bog and plateau bog wetland types, results in large areas of fire-dependent landscape features in the western portion of the Low Sub-arctic in the Hudson Bay Lowland (Riley 1982).

The low regional gradient of only 0.65 to 1.0 m/km (Riley 1982) results in a near-level wetland plain with generally flat wetland surfaces. Lateral spreading of the unconfined peat mass may prevent significant doming in bogs, other than due to localized permafrost effects. Thus, the thickness of the peat in the Lowland is less than wetlands which occur in similar climatic regimes but are confined. The peat thickness is known to be at least 3 m (Table 3.2.5) and may reach over 4 m in older more southerly areas (Tarnocai 1984).

Peats are dominantly mesic (von Post 3 to 6) although fibric peats commonly form the uppermost layer throughout the Lowland. Soils are a mixture of orthic and humic gleysols in marshes and swamps, terric mesisols in coastal fens and typic mesisols where peat depths reach 140 cm.

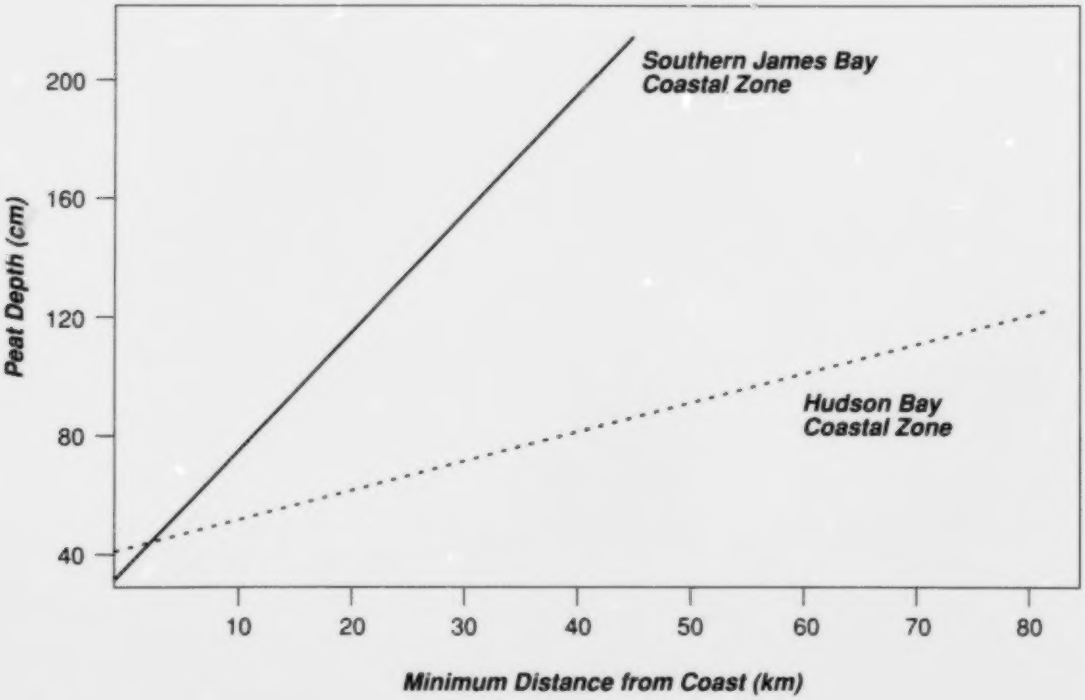
Peat depth increases continuously from the coast inland with relatively higher accumulation rates toward the south (Wickware *et al.* 1980). Figure 3.2.2 illustrates the relationship between peat depth with distance from the coast for two areas in the Lowland based on measurements taken in fens. Increasing distance inland represents a longer time since uplift of land from the sea due to isostatic rebound. In the southern James Bay area (Low Sub-arctic) the rate of peat accumulation is more than twice as fast as the area along the south shore of Hudson Bay (High Sub-arctic).

Gently sloping, thin (less than 1 m) organic veneer bogs dominate the lacustrine plains of the Kazan Upland in Manitoba (Mills *et al.* 1976b). Both mesic and fibric peats are common in this area with fibric peats in the upper portion of the veneer bogs overlying mesic fen peats (area A, Table 3.2.5). This wetland area is contiguous with the Hudson Bay Lowland allowing the extension of unconfined peatlands outside the area of the Lowland. Overall, wetlands occupy between 26 and 75 percent of the area of the lacustrine sediments within the Low Sub-arctic Wetland Region. Peat depths are comparable to the Manitoba portion of the Lowland but shallower than the central and southern portions in Ontario. The Canadian Shield areas of Manitoba and Québec have only minor wetland development. The areal coverage for the Québec portion is shown as 6 to 25 percent and is probably not more than 10 percent in total (Gilbert *et al.* 1985). The largest wetland area is located close to James Bay to the north of La Grande Rivière. Bog veneers are typical with soils including Mesic Organic Cryosols and Terric Mesisols (Zarnovican and Belair 1979).

The active layer reported for permafrost peatlands within the Low Sub-arctic Region is mostly in the range of 40 to 60 cm (National Wetlands Working Group 1986, Mills *et al.* 1976a). Brown (1968) noted that the active layer in peatlands of the Shield were thicker, on average, than in the Hudson Bay Lowland. However, some of his sites may have been located in the High Boreal Wetland Region. Cowell *et al.* (1982) recorded an active layer 70 cm thick in the central Lowland southwest of Peawanuck, Ontario.

FIGURE 3.2.2

Relationship between distance from the coast and depth of peat as measured in fen types for the Hudson Bay Lowland. Data presented for the area south of the Albany River in the south-western James Bay area (Low Sub-arctic Wetland Region) and in the vicinity of the Winisk River (High Sub-arctic Wetland Region) (modified from Wickware & Associates Inc. 1990).



Surface water cover tends to be greater for Canadian Shield areas than for the Hudson Bay Lowland, however, the estimates in Table 3.2.5 have been compiled using different methodologies. The estimate for the Lowland is based on a detailed count and area measurement of lakes greater than 10 ha using 1:250,000 scale maps (Cox 1978). Estimates for the other areas shown in Table 3.2.5 have been derived mostly from visual interpretation of various map sources.

The ecology of Low Sub-arctic palsa bogs in the Hudson Bay Lowland of Ontario has been investigated by Railton and Sparling (1973). They describe the vegetation and morphology of palsas and provide data on the energy exchange during July for mature, partially eroded and collapsed palsas. Based on morphology and radiocarbon dating of peat, Railton and Sparling (1973) conclude that the largest palsas are recent in age (about 200 years). Sims and Stewart (1981) present the results of detailed biomass calculations contrasting disturbed and undisturbed conditions (i.e., cutover and non-cut) for a peat plateau bog at the southern edge of the Low Sub-arctic Wetland Region in Manitoba.

3.2.2.3 WETLAND TYPES

Characteristic wetlands are peat plateau bog, palsa bog, flat bog, veneer bog, ribbed and horizontal fens. Marshes and swamps are common in the Hudson Bay Lowland. The marshes of the Hudson Bay Lowland include both salt marshes and freshwater meadow marshes which parallel the western and southern shore of James Bay. Veneer bog peatlands are common in the lacustrine plain of Manitoba and on the Shield in Québec (Table 3.2.5). Water chemistry, depth to the water table and peat thickness data for horizontal fens, flat bogs and conifer swamps in the Ontario Hudson Bay Lowland portion of the Low Sub-arctic Wetland Region are provided in Table 3.2.6.

Swamp

Within both the High and Low Sub-arctic Wetland Regions, swamps develop along the edges of streams and immediately inland of river levées.

Swamps are either dominated by a dense growth of trees, primarily black spruce (*Picea mariana*), or by abundant shrubs such as willow (*Salix* spp.) and alder (*Alnus* spp.) without any tree growth. Shrub swamps

TABLE 3.2.6

Mean (standard deviation) for groundwater chemistry, peat thickness and depth to water table for conifer swamp, fen and bog types in the Low Sub-arctic portion of the Ontario Hudson Bay Lowland (south of the Albany River). Graminoid fens, low shrub fens and treed fens are horizontal fens whereas treed bogs are primarily flat bogs.

PARAMETERS	CONIFER SWAMP	TREED BOG	TREED FEN	GRAMINOID FEN	LOW SHRUB FEN
No. of Stands	14	10	19	12	16
Distance from Coast (km)	24(15)	26(9)	27(11)	19.8(19)	9.3(16)
Peat Depth (cm)	79(26)	120(61)	126(45)	103.4(56)	98.8(36)
Groundwater pH	6.0(1.6)	4.2(1.0)	5.7(0.7)	2.9(0.9)	10.3(0.8)
Specific Conductance (μmhos)*	126(103)	50(19)	67(48)	140(24)	200(183)
Major Ions and Nutrients:					
Ca^{++} (mg/l)	21.7(14.3)	4.9(5.7)	10.4(10.9)	21.9(12.1)	16.6(12.5)
Mg^{++} (mg/l)	5.2(4.4)	0.8(0.8)	1.8(1.8)	4.1(2.1)	5.4(5.3)
Na^{+} (mg/l)	10.2(10.3)	1.8(1.4)	4.5(3.8)	8.7(8.6)	20.3(15.9)
K^{+} (mg/l)	1.6(0.9)	1.3(0.5)	1.8(16)	1.1(0.4)	2.6(1.2)
$SO4^{--}$ (mg/l)	3.2(1.9)	6.7(3.9)	2.8(1.7)	2.0(1.5)	1.6(1.2)
Cl^{-} (mg/l)	18.4(18.8)	5.1(1.9)	8.1(6.3)	12.6(10.2)	33.2(26.2)
Fe^{++} (mg/l)	11.3(18.6)	2.0(3.0)	14.9(34.3)	18.0(13.6)	22.9(25.3)
Mn^{+} (mg/l)	0.7(0.9)	0.2(0.2)	0.3(0.2)	0.9(1.2)	0.3(0.2)
Total Kjeldahl N (mg/l)	1.2(0.6)	1.2(0.4)	1.2(0.6)	1.1(0.7)	1.7(0.9)
Total P (mg/l)	0.4(0.3)	0.4(0.2)	0.3(0.2)	0.2(0.1)	0.4(0.2)
Soluble Si (mg/l)	2.7(2.0)	1.5(0.6)	1.3(1.4)	3.5(3.0)	3.6(3.8)

SOURCE: Sims *et al.* 1982a and 1982b

* At 25°C, corrected for H^{+}.

tend to form along the margin of small streams whereas treed swamps occur most frequently along the outer edge of river levées and along larger streams (Wickware & Associates Inc. 1990).

Swamps are characterized by a wide range in water table depth, peat thickness and nutrient status. Generally, swamps which form the margins of small streams have gleysolic mineral soils with no peat accumulation. These sites are flooded early in the year due to snow melt but water levels decline throughout the year. The water table in these swamps can be up to 60 cm or more below the surface. Nutrient status is high due to the presence of carbonate-rich alluvium and periodic flushing by stream water.

Swamps dominated by abundant tree growth (conifer swamp) have peat accumulations which average 79 cm (Table 3.2.6) but they are highly variable (between 24 and 123 cm in the southeastern Lowland). The water table occurs within the organic material about 24 cm below the surface, on average. Nutrient status in these swamps is generally lower than those dominated by shrubs. This reflects the abundance of organic material which isolates the living vegetation from the rich alluvial substrate. However, they are among the richest peatland types because periodic flooding serves as a source of nutrients.

Horizontal Fens

These minerotrophic wetland forms are structureless with flat surfaces devoid of open water. They are dominated by low shrubs, graminoids or tamarack (*Larix laricina*) and range in nutrient status from poor to rich based on calcium concentrations and pH (see Section 3.3.1). They reach their greatest expression in the Hudson Bay Lowland due to the presence of vast expanses of featureless terrain in combination with broad groundwater seepage zones. They are best developed inland of the freshwater marshes of James Bay and near the estuaries of major rivers.

Low shrub fens have a cover of at least 25 percent of low shrubs consisting mostly of willow species and dwarf birch (*Salix pedicellaris, S. candida* and *Betula glandulosa*). Graminoid fens are dominated by grasses, sedges and non-sphagnum mosses. Characteristic vegetation includes cotton grass (*Scirpus hudsonianus*), sedges (*Carex limosa, C. exilis*), horsetail (*Equisetum fluviatile*) and brown moss (*Scorpidium scorpioides*). Tamarack fens ('treed fens') are distinguished by the presence of a tree stratum which, without exception, is predominantly composed of tamarack (*Larix laricina*). Other dominants of tamarack fens include dwarf birch, leather leaf (*Chamaedaphne calyculata*), sedges (*Carex chordorrhiza*), horsetail and sphagnum mosses (*Sphagnum warnstorfii*) (Sims *et al* 1982b).

Graminoid fens are generally the richest of the horizontal fen types and intermediate in peat depth. The pH of graminoid fens ranged from 4.4 to 7.3 (mean of 6.6 for 12 sites) and peat depths ranged from 32 to 216 cm (mean of 103.4 cm). Low shrub fens have the shallowest peat depths with an average groundwater pH of 6.0. Tamarack fens have the deepest peats and poorest groundwater chemistry (Table 3.2.6). Average depth to water table for the fen types varies from 2.9 cm to 16 cm; it is deepest in treed fens and shallowest in graminoid fens (Table 3.2.6). The water table is generally not above the surface of these fens except during spring melt.

Terric and Typic Mesisols are the dominant soil types in these horizontal fens although Terric Fibrisols occur in the shallower graminoid and shrub-rich types. Peat material consists primarily of weakly decomposed sedges with an upward transition to undecomposed sphagnum peats in tamarack fens.

Channel Fens

Channel fens are minerotrophic wetlands which serve as drainage routes for groundwater supplied from flat bogs, palsa bogs or peat plateau bogs. In upland areas they are confined to low-gradient, narrow channels defined by bedrock outcrops or surficial landforms. The groundwater seepage zone tends to be very restricted (i.e., narrower) compared to horizontal or ribbed fens. Channel fens are unfrozen and usually flat and featureless. Narrow pools or flarks oriented parallel to the direction of groundwater flow may occur. They are found in a wide range of wetland regions including the High and Low Sub-arctic as well as the High Boreal.

Zoltai *et al.* (1988a) note that the vegetation of channel fens is characteristic of nutrient-rich sites due to the influence of minerotrophic waters from surrounding or underlying mineral soils. On the drier sites within Low Sub-arctic channel fens, tree species such as *Larix laricina* and cedar (*Thuja occidentalis*) along with shrubs such as dwarf birch (*Betula glandulosa*) are common. Abundant sedges, graminoids and mosses occupy the wettest sites. Trees and shrubs are absent in channel fens of the High Sub-arctic region.

Soils in these fens are dominantly Fibric Mesisols having fibric surface peats underlain by moderately to well decomposed peat (Zoltai *et al.* 1988a). Peat ranges in thickness from about 40 cm to an average in excess of 3 m.

Zoltai *et al.* (1988a) describe a channel fen which is located in the Manitoba portion of the Hudson Bay Lowland (56°39' N, 93°03' W). The peat thickness was 185 cm and the water table varied from surface level to 15 cm below the surface. The upper 45 cm consisted of weakly decomposed sphagnum peat which graded into mixed sphagnum and sedge peat which formed under forested conditions. Moderately decomposed fen peat plus small twigs formed the thickest peat layer with a thin strata of well-decomposed peat immediately above the mineral soil.

Flat Bog

Flat bogs are ombrotrophic wetlands which have very uneven, hummocky surfaces due to an abundance of mound-forming sphagnum mosses. They can be open, dominated by low shrubs, or treed. Bog pools are present in high raised-centre bogs and generally absent in low bogs in which the surface is close to the level of the surrounding fen. Permafrost is not present in these peatlands although insulation provided by trees and thick sphagnum mosses can delay melting of seasonal frost several weeks later than in surrounding fens (Cowell *et al*. 1978). Flat bogs occur in the southernmost portion of the Low Sub-arctic Wetland Region and in the High and Mid Boreal Wetland Regions.

Sphagnum mosses, particularly *Sphagnum fuscum* and *S. rubellum*, as well as woody shrubs including Labrador tea (*Ledum groenlandicum*) and leather-leaf (*Chamaedaphne calyculata* and *Kalmia polifolia*) dominate. Black spruce (*Picea mariana*) forms the tree layer in raised treed bogs as well as wooded palsas and peat plateaus.

Flat bogs described by Sims *et al*. (1982a) for the southern portion of the Low Sub-arctic Wetland Region have an average groundwater pH of 4.2 (Table 3.2.6). Bog peats are dominated by undecomposed sphagnum peat. Weakly decomposed sedge peat is the next most common peat type, however, unlike the fen types there may also be a strong forest peat component (i.e., abundant wood fragments plus a mixture of sedge and non-sphagnum moss peat). In some profiles, forest peat forms the lowest peat layer. Forest peats indicate the presence of a shrub or tree component within the living community at the time the peat accumulated. Peat thickness is variable ranging from as little as 52 cm nearest the coast of James Bay to over 200 cm 40 km inland from the coast. The depth to the water table is the deepest of all wetland types of southern James Bay including fens, marshes and swamps, ranging between 13 and 37 cm. Relatively deep water tables are common in bogs because of their very hummocky nature and relatively fast accumulation of sphagnum peat.

Veneer Bogs

These bogs are ombrotrophic wetlands. Within the Low Sub-arctic Wetland Region, they are most common in the lacustrine plain of northern Manitoba and on the Canadian Shield in Québec (Table 3.2.5). Veneer bogs are also characteristic of the northern portion of the High Boreal Region. They form on the mid to lower portion of gently sloping terrain and vary in thickness to a maximum of about 1.5 m (Zoltai *et al*. 1988a). Veneer bogs typically cover large areas, up to several square kilometres in extent. They are characterized by relatively flat surfaces interspersed with distinct parallel lineations oriented downslope. These lineations are marked by vegetational differences which are probably due to a minerotrophic influence from slightly enhanced drainage along the lineation. However, there is little or no change in relief across the lineations.

Vegetation consists of typical bog species. The lineations are marked by a line of taller trees along their margin and by a greater diversity of plant species (Zoltai *et al*. 1988a). Generally more minerotrophic species such as tamarack (*Larix laricina*), white birch (*Betula papyrifera*), shrubs including willows (*Salix* spp.) and alders (*Alnus* spp.), sedges and certain mosses occur within the area of the lineation. Zoltai *et al*. (1988a) suggest that the enhanced tree growth and rich plant assemblage of the runnels indicate their role as drainageways through the bog with associated swamp-like conditions.

These bogs are not formed by the action of permafrost but patches or lenses of permafrost may be present. They originated as minerotrophic fens; ombrotrophic conditions became established as a result of thickening peat accumulations which isolated the living surface from the influence of the mineral soil. Paludification of surrounding upland terrain by these bogs is common as the peat thickens and its associated spruce forest with mixed moss cover expands upslope.

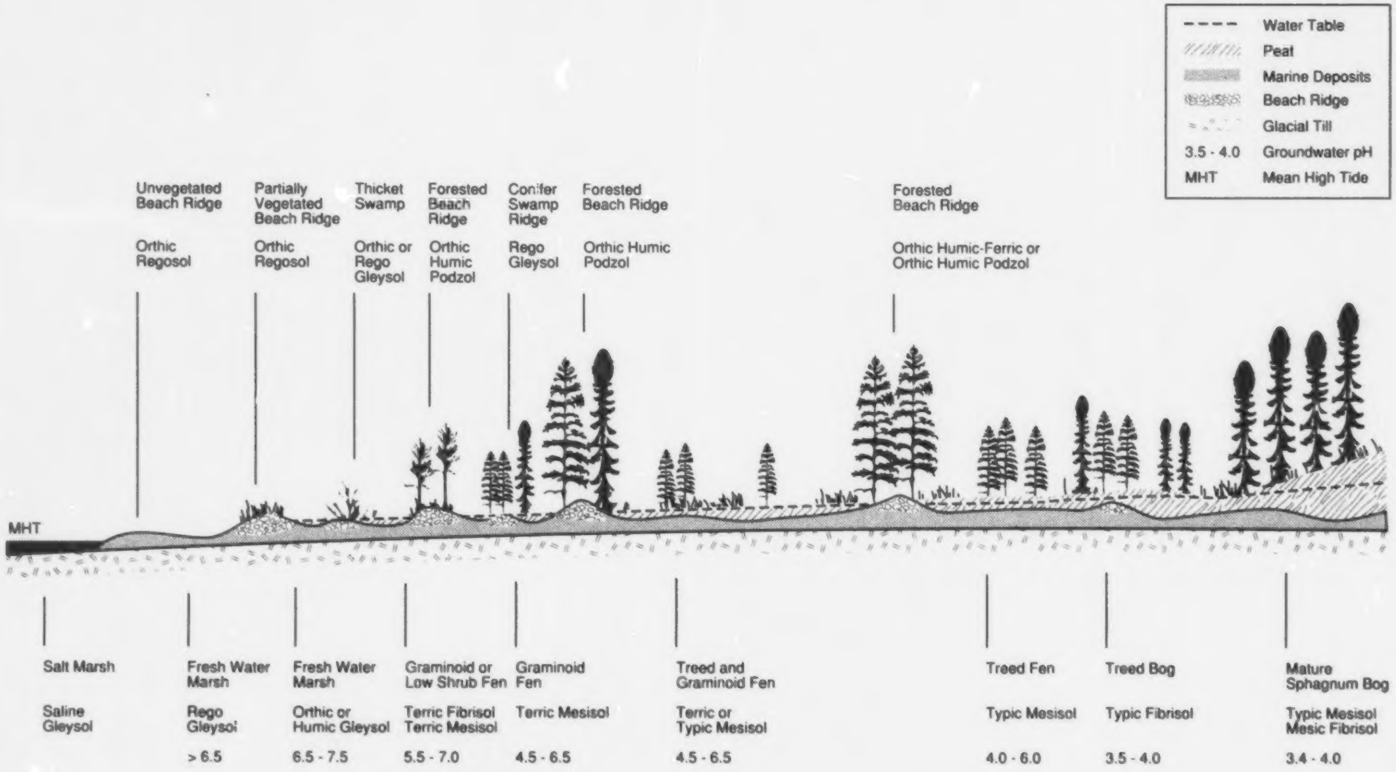
3.2.2.4 LOW SUB-ARCTIC TOPOSEQUENCE

Figure 3.2.3 is a schematic toposequence illustrating relationships among landform, soils, wetland and upland physiognomic types, and groundwater pH for a portion of the Low Sub-arctic Wetland Region. The area represented is the southernmost portion of the region in the Hudson Bay Lowland. It illustrates a schematic cross-section inland from the coast of southwestern James Bay.

This portion of the Low Sub-arctic region is undergoing active uplift in the order of about 1 m/100 years

FIGURE 3.2.3

Schematic cross section through the Low Sub-arctic Wetland Region representing the Hudson Bay Lowland portion near Moosonee, Ontario (modified from Wickware *et al.* 1980).



due to glacioisostatic rebound. Thus, it illustrates a time sequence increasing from left to right in the diagram (Figure 3.2.3).

The lowest substrate is a glacial till overlain by undifferentiated marine deposits. These typically consist of clayey-silts in the swales and coarse sands and gravels on beach ridges. Nearest the coast, upland and mineral soil wetlands dominate the landscape. Wetlands include salt marsh, freshwater marsh and shallow horizontal fens.

The landscape becomes progressively paludified toward the interior such that only the highest beach ridges (as well as river levées) remain above the surface of the peat blanket. The increase in peat thickness is accompanied by a dramatic change in the surface vegetation which reflects the gradual isolation of the living surface from minerotrophic influences. This is illustrated by the transition through various horizontal fen types, (in a general sequence from low shrub fen through graminoid fen to treed fen), to the establishment of ombrotrophic flat bogs. The pH gradient readily reflects these conditions.

Image 3.2.2 shows the area of southwestern James Bay in the Hudson Bay Lowland. It includes portions of both the Low Sub-arctic and the Mid Boreal Wetland Regions. The Low Sub-arctic toposequence, as described above, is represented by the medium-toned, smooth-patterned area paralleling the coast. The smooth patterns on either side of the Moose River represent large areas of horizontal fens (mostly treed fens) which are drained by numerous parallel streams. The Mid Boreal Wetland Region forms most of the image with the Kinosheo Lake research site located in the left centre. The Mid Boreal of this area is represented by mature bog and fen complexes. Medium to dark tones are graminoid fen drainageways and the lighter areas are lichen-dominated open and shrub-rich treed bogs.

3.2.3 ATLANTIC SUB-ARCTIC WETLAND REGION

3.2.3.1 ENVIRONMENTAL SETTING

Physiography

The Atlantic Sub-arctic Wetland Region within the Northern Wetlands Study area is represented by the eastern portion of the Mecatina Plateau Physiographic Division along the coast of Labrador (Section 2.5.2). The terrain is rugged, particularly toward the south, rising rapidly from the Atlantic to elevations of between 200 and 375 m immediately inland (Bostock 1970). The southern half of the coast is characterized by numerous islands, an extremely irregular shoreline and a barren rock surface (Lopoukhine *et al.* 1978). Along the northern portion of the coast, as far north as Lake Melville, are large areas of glacial sands and gravels overlying marine clays which form bluffs (Lopoukhine *et al.* 1978). The marine clays inhibit drainage resulting in the development of large organic complexes near the coast. Inland, the sand plains consist of deep, well drained sands interrupted only by eskers and wind-eroded beach ridges. Rivers are incised into the plain and occupy narrow valleys.

Further inland the topography becomes bedrock-controlled with a thin veneer of coarse morainal material. This topography is characterized by poor drainage and, consequently, the development of large areas of organic terrain. The Canadian Shield forms the bedrock geology for this wetland region with anorthosite, granitic gneiss and gneiss forming the dominant rock types (Lopoukhine *et al.* 1978).

Climate

The Atlantic Ocean has a significant influence on the climate of the Atlantic Sub-arctic Wetland Region. The January and annual mean temperatures are higher than the High and Low Sub-arctic Regions but the mean July temperature is lower. Total precipitation is also greater than the two other Sub-arctic regions.

Due to the maritime influence, there is a sharp contrast between coastal and inland sites. The climate statistics summarized in Table 3.2.7 are representative of coastal sites since there are no climate stations inland. However, some general comments can be made on the characteristics of the climate of inland locations.

TABLE 3.2.7

Atlantic Sub-arctic Wetland Region climate statistics*

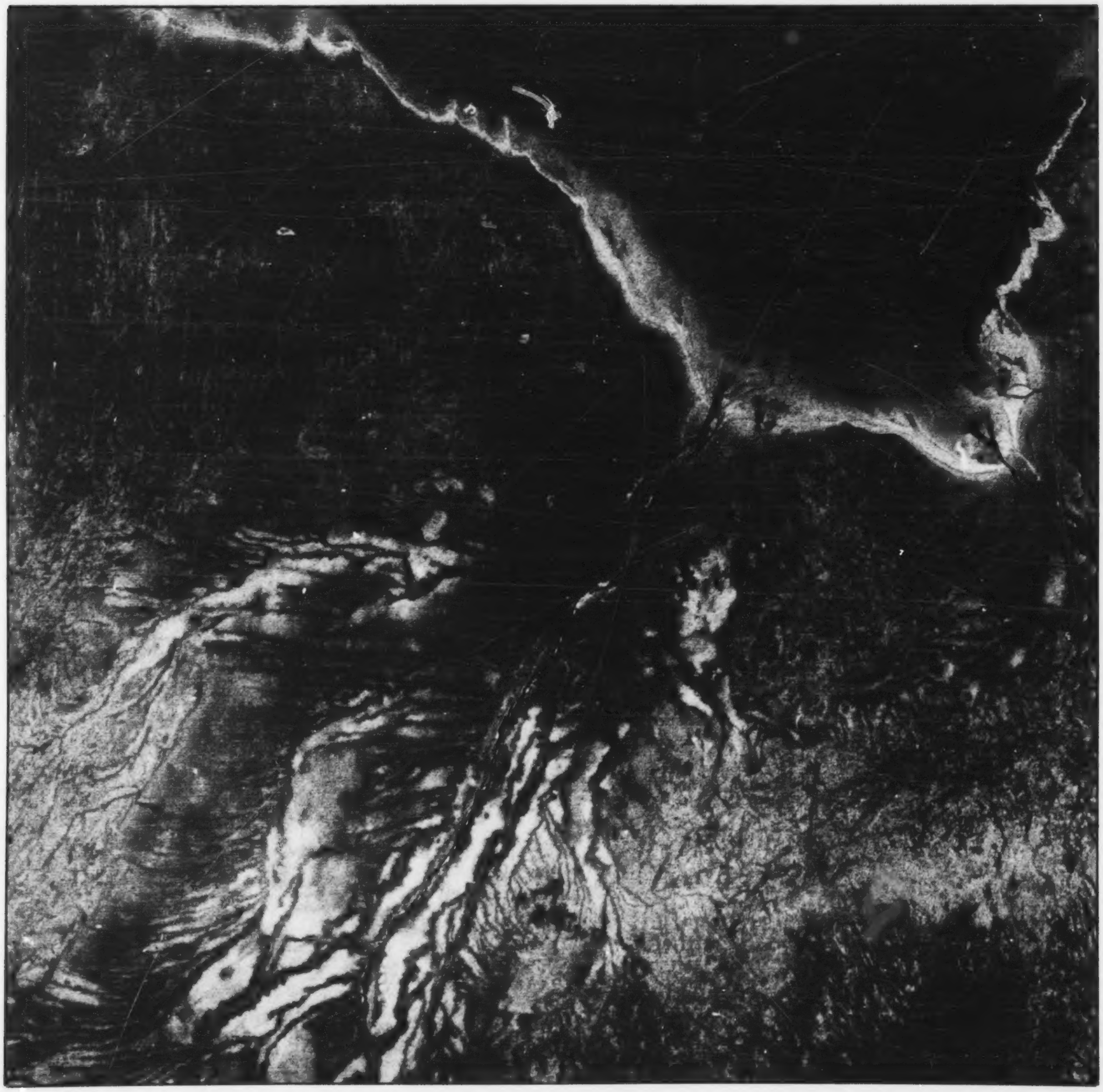
CLIMATE ELEMENT	Mean	Range
Bright Sunshine (hours)**	1464	-
Precipitation (mm) — Annual	834	740 to 954
Snowfall (cm) — Annual	427	417 to 440
Temperature (°C) — Annual	-1.6	0.0 to -2.9
— January	-15.4	-13.2 to -17.0
— July	11.0	9.8 to 12.7
Growing Degree-days (°C)	560	433 to 727
Growing Season (days)	126	100 to 143
Freeze-free days (days)	113	88 to 130

* Statistics compiled for the period 1951 to 1980 from 3 stations within the Low Sub-arctic region of the Northern Wetlands Study area.

** Based on 1 station.

IMAGE 3.2.2

Landsat multispectral image (bands 4, 5 and 7) of the Low Sub-arctic and Mid Boreal of southwestern James Bay. The townsite of Moosonee is located on the west bank of the Moose River approximately 20 km upstream of James Bay (light tone on outside of river bend). Kinosheo Lake is the large lake located in the left centre of the image. The image was recorded on September 29, 1976 and is at a scale of 1:1 million.



Coastal sites, generally, are warmer than inland sites which are more continental. They also have a longer frost free period and, hence, a longer growing season. Inland sites have a greater range in annual temperature; winter temperatures are colder at exposed plateau and mountain areas of the interior while their summer temperatures can be warmer. Proximity to the ocean moderates temperature. Fall at coastal locations is prolonged due to the heat storage capacity of the ocean while summer temperatures are modified by the cold Labrador Current.

Precipitation in the coastal areas of this region is quite pronounced, averaging 834 mm. Snowfall comprises approximately 50 percent of the total precipitation. Total annual precipitation decreases in more northerly latitudes and at inland locations.

Vegetation, Soils, Permafrost and Wildlife

Upland forests along the coast of the Atlantic Sub-arctic Wetland Region are dominated by white spruce (*Picea glauca*) with a ground cover of lichens on dry sites and mosses on moister sites (Ecoregions Working Group 1989). Tamarack (*Larix laricina*) and black spruce (P. *mariana*) replace white spruce, which is more tolerant of salt spray, as the dominant trees in interior locations (Lopoukhine *et al.* 1978). Balsam fir (*Abies balsamea*) is rare but also occurs in interior sites. Although the climate is moderated by the Atlantic Ocean, trees tend to be stunted, open grown and limited to sheltered areas. Forest vegetation is replaced by alder (*Alnus* spp.), dwarf birch (*Betula glandulosa*) and Labrador tea (*Ledum groenlandicum*) following frequent burning (Ecoregions Working Group 1989). Large areas of this wetland region are characterized by exposed bedrock and very shallow soils. These sites have stands of black spruce with an understorey of shrubs such as *Kalmia polifolia* and blueberry (*Vaccinium angustifolium*) along with a ground cover of lichens and mosses (Ecoregions Working Group 1989). This region lies within the Forest-Tundra Section of the Boreal Forest Region as defined by Rowe (1972). Wetlands are dominated by salt marshes along the coast and bogs further inland.

Soils are primarily Podzols on well-drained coarse textured materials, Brunisols on moderately drained to imperfectly drained finer-textured materials and Gleysols on imperfectly to poorly drained sites including coastal salt marshes. Fibric and Mesic Organic soils occur in interior wetlands. Organic Cryosols are sporadic being limited to occasional palsa bogs. The portion of the Atlantic Sub-arctic Wetland Region within the Northern Wetlands Study area lies in the southern portion of the zone of scattered permafrost (Section 2.6.2).

The Labrador coast in the study area lies within the Atlantic migratory flyway. Species most common to the region include Atlantic puffin, seal and polar bear along the coast with Canada goose, moose, lynx, black bear, red fox and caribou further inland (Ecoregions Working Group 1989).

3.2.3.2 WETLAND CHARACTERISTICS

The dominant wetland types, soil characteristics and overall wetland distribution for the Atlantic Sub-arctic are summarized in Table 3.2.8. The wetlands of this region have a greater affinity with those of the Atlantic Boreal than with the other Sub-arctic regions. Palsa bogs are the primary wetland type common to Atlantic and other Sub-arctic wetland regions, however, their floristics vary slightly. Differences between coastal and interior wetlands are the result of oceanic influences related to climate and nutrient input. Wells and Hirvonen (1988) note that these coastal areas are characterized by greater precipitation and higher nutrient inputs as a result of sea spray effects. Hence, shallow bogs may have small areas of minerotrophic fen species and many of these peatlands are transitional between true bog and poor fen (Wells and Hirvonen 1988).

Wetland coverage within this region ranges from 6 to 25 percent with gently sloping bog types dominating. Wet soils are primarily Organic Cryosols (in palsas) and Typic Mesisols with peat depths averaging 200 cm (Table 3.2.8). The soil climate is identified by Clayton *et al.* (1977) as cold cryoboreal which is closer to those of the Boreal Wetland Regions than the other Sub-arctic Regions. Surface water cover in the Atlantic Sub-arctic is generally low with large portions less than 10 percent (Lopoukhine *et al.* 1978).

3.2.3.3 WETLAND TYPES

The dominant wetland types of the Atlantic Sub-arctic are Atlantic plateau bog, string bog and palsa bog. String bog is described under the Atlantic Boreal Section (3.3.4).

Atlantic Plateau Bog

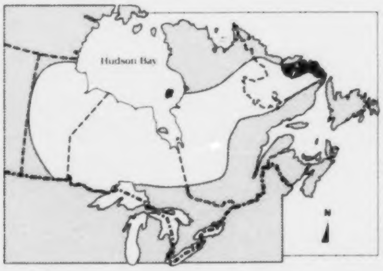
Atlantic plateau bogs are ombrotrophic peatlands with a flat to hummocky, plateau-like surface raised above surrounding terrain (Wells and Hirvonen 1988). Large round bog pools are a common feature. They commonly occupy shallow depressions with peat depths of 2 to 4 m. The surface peat consists of moderately decomposed sphagnum and/or sphagnum-sedge

TABLE 3.2.8

Wetland and soil characteristics of the Atlantic Sub-arctic Wetland Region

	CANADIAN SHIELD
WETLAND TYPES	Atlantic Plateau Bog, String Bog Palsa Bog
WETLAND DISTRIBUTION (%)	6 to 25
MORPHOLOGY/SLOPE	hummocky/gently sloping
DEPTH OF PEAT (cm)	200 (average)
DECOMPOSITION	fibric and mesic
WETLAND SOILS	Terric Mesisol and Fibrisol Typic Mesisol
SOIL CLIMATE (Temp./Moisture)	Cold Cryoboreal/Perhumid
MEAN ANNUAL GROUND TEMPERATURE (°C)	4.4 (Newfoundland Coast)
ACTIVE LAYER THICKNESS (cm)	-
SURFACE WATER COVER (%)	0 to 20

SOURCES:
Lopoukhine *et. al.* 1978; National Wetlands Working Group 1986;
Wells and Hirvonen 1988; Young and Judge 1985.



remains overlying a more humified sphagnum-sedge peat. The surface of the bog is relatively flat with margins sloping 20 to 30 percent (Pollett and Wells 1981).

Vegetation of hummocks include cloudberry (*Rubus chamaemorus*), sheep-laurel (*Kalmia angustifolia*), crowberry (*Empetrum nigrum*), blueberry (*Vaccinium angustifolium*), sphagnum mosses (*S. fuscum*, and *S. rubellum*) and lichens (*Cladina* spp.) (Wells and Hirvonen 1988).

Palsa

Palsas of the Atlantic Sub-arctic occur as palsa bogs, palsa fens and smaller frozen mounds within Atlantic plateau bogs (Wells and Hirvonen 1988). They are commonly 1 m high and 2 to 3 m long. Characteristic vegetation is bog-bilberry (*Vaccinium uliginosum*), cowberry (V. *vitis-idea*), sweet gale (*Myrica gale*), sedges (*Carex rariflora* and *Eriophorum spissum*) and several lichens including *Cetraria nivalis, Ochrolechia frigida, Sphaerophorus globosus, Rhacomitrium lanuginosum, Cladonia uncialis, C. boryi, Alectoria nigricans, Cornicularia aculeata* and *Ptilidium iliare* (Wells and Hirvonen 1988).

3.2.3.4 ATLANTIC SUB-ARCTIC TOPOSEQUENCE

Figure 3.2.4 illustrates soil-landform-vegetation relationships for a typical Atlantic plateau bog. These bogs along with string bogs (Section 3.3.4) are the most common peatland types of most of Labrador. Atlantic plateau bogs are common in western and northern Newfoundland where they generally occur without permafrost. In the Atlantic Sub-arctic Wetland Region of Labrador they often have either frozen mounds or palsas (Wells and Hirvonen 1988). These bogs develop in relatively flat to gently undulating terrain consisting of sandy glaciofluvial outwash deposits, marine terraces (such as south of Lake Melville) and between ridges of till covered bedrock (Pollett and Wells 1981).

3.3 BOREAL WETLANDS

By far the greatest portion of the Northern Wetlands Study area consists of boreal wetlands. They occupy approximately 60 percent of the study area and consist of four regions: High, Mid, Low and Atlantic Boreal (Map 3.1.1). The Boreal Wetland Regions are dominated by Arctic air masses during the winter and Pacific or tropical air masses in the summer (Hare and Ritchie 1972). The progression from High to Low Boreal wetland region represents increasingly milder temperatures and higher net solar radiation (Section 2.3.1 and 2.3.2).

The Atlantic Boreal Wetland Region lies to the east of the other Boreal regions in central Québec and southern Labrador. Climatically, this region is characterized by higher total precipitation than those to the west (Section 2.3.5). Although identified as a boreal wetland area by the National Wetlands Working Group (1986), the Ecoregions Working Group (1989) have included most of the Atlantic Boreal Wetland Region within the Low Sub-arctic Ecoclimatic Region on the basis of climate and vegetation.

Forests within boreal ecoclimatic regions are dominated by black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*) and white spruce (P. *glauca*).

Zoltai (1988) describes the boreal wetland regions as follows:

> "... cold winters but warm summers... Amounts of precipitation are moderate in the centre of the continent, but become high in maritime coastal areas. Although basically similar wetlands occur throughout the four boreal wetland regions, a thermal differentiation is apparent, as small permafrost bodies can still be found as palsa and peat plateau bogs in the High Boreal Wetland Region."

The areas of greatest wetland development in the High Boreal occur on the Manitoba and Ontario glaciolacustrine plains and in the south-central Hudson Bay Lowland. In the Low Boreal, wetland development is best expressed on the Manitoba Plains, the southwestern Hudson Bay Lowland and the glaciolacustrine plains of Ontario and Québec (Mid Boreal). Significant wetland development also occurs on the glaciolacustrine sediments of southeastern Manitoba in the Low Boreal and on drumlinized till plains in the central Labrador portion of the Atlantic Boreal.

3.3.1 HIGH BOREAL WETLAND REGION

3.3.1.1 ENVIRONMENTAL SETTING

Physiography

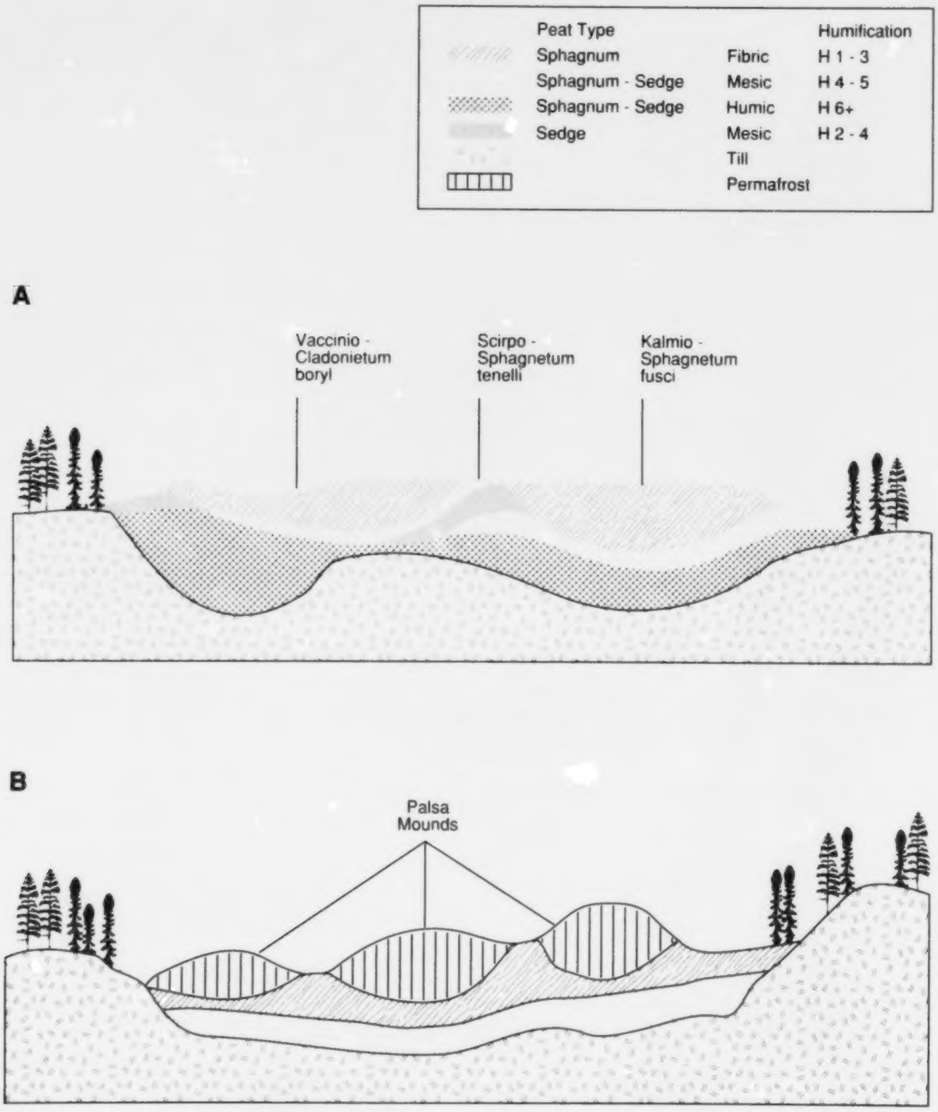
West of James Bay, the High Boreal Wetland Region consists of the Kazan Upland, Severn Upland and approximately 40,000 km^2 of the southern Hudson Bay Lowland Physiographic Divisions (Section 2.5.2). The uplands are characterized by exposed bedrock of the Canadian Shield, bedrock/ground moraine complexes

FIGURE 3.2.4

Toposequence for the Atlantic Sub-arctic Wetland Region (Atlantic plateau bog)

(A) Cross-section of bog-landscape morphology, peat type, peat humification and major vegetation types (from Pollet and Wells 1981).

(B) Cross-section showing occurence of palsas typical of Atlantic plateau bogs in Labrador (from Wells and Hirvonen 1988).



and widespread low-relief areas covered with glaciolacustrine sediment. The Lowland is a glaciomarine coastal plain (Section 2.5.4).

Moraine deposits in Québec are composed only of low-base Shield materials, however, in Ontario and Manitoba, the ground moraine is composed of both locally derived non-calcareous Shield rocks and Paleozoic limestones. Calcareous limestones originated to the north and northeast in the Hudson Platform (Section 2.5.3). They were carried southward by the Pleistocene glaciers and deposited on the Shield. Hence, the tills of this wetland region, in Ontario and Manitoba, are calcareous. The relative proportion of carbonate material within the till increases toward the northeast as distance from the Hudson Bay Lowland decreases (Veldhuis *et al.* 1979).

Drumlinized till plains with glaciolacustrine deposits flanking the lower portions of the drumlins are common in central Manitoba (Mills *et al.* 1978a and b). Level to gently sloping veneer bogs are common on the most poorly drained portions of these drumlinized till plains. Other areas of central Manitoba and northwestern Ontario are gently undulating to hummocky with shallow to deep, moderately calcareous glaciolacustrine deposits. These areas are also ideal for wetland development and include veneer bogs, peat plateau, horizontal fens and northern ribbed fens (Veldhuis *et al.* 1979). Lake shorelines are generally irregular and rocky with bedrock hills scattered throughout (Wickware and Rubec 1988). Bedrock varies from granite and granitic gneiss to volcanic and metasedimentary rocks (Section 2.5.3). Glaciomarine silts and clays form the substrate beneath the extensive organic deposits of the Hudson Bay Lowland. The Lowland is described in detail in Section 3.2.2.

Eastward from James Bay this wetland region consists of portions of the Eastmain Lowland, Larch Plateau and Lake Plateau Physiographic Divisions, respectively. The area within the Larch and Lake Plateaux consist of typical Shield as described for the Québec portion of the Low Sub-arctic Wetland Region (Section 3.2.2). The Eastmain Lowland represents the area inundated by the glaciomarine Tyrrell Sea. The topography is much more subdued with extensive deposits of clay and silt similar to the Ontario side of James Bay. Wetlands are widespread on these fine-grained sediments. The main difference from the Hudson Bay Lowland is the presence of low bedrock hills which break the otherwise gently sloping surface. The bedrock consists of Shield granites and granitic gneisses as compared to the flat-lying sedimentary limestones and dolomites of the Hudson Bay Lowland.

Climate

The transition between Sub-arctic, and Boreal vegetation occurs along the mean position of the July Arctic Front. This is the zone where dominance of Arctic airstreams changes to Pacific airstreams. Boreal vegetation usually occurs where Arctic air masses dominate for 6 to 10 months of the year (Bryson and Hare 1974).

Table 3.3.1 presents climate statistics for the High Boreal Wetland Region. Winters in the region are cold (−21.7 to −26.9°C mean January temperature). Total precipitation and snowfall increase from west to east with snowfall comprising approximately 36 percent of total precipitation. Hours of bright sunshine, however, decline from west to east.

There is a significant difference, climatically, between the Québec portion (Humid High Boreal) and the west-

TABLE 3.3.1

High Boreal Wetland Region climate statistics*

		WETLAND SUBREGIONS					
		HUMID		CONTINENTAL		COMBINED	
CLIMATE ELEMENT		Mean	Range	Mean	Range	Mean	Range
Bright Sunshine (hrs)**		1530	-	2006	-	1768	1456 to 2011
Precipitation (mm)	— Annual	675	533 to 784	545	464 to 666	479	464 to 784
Snowfall (cm)	— Annual	222	181 to 306	207	141 to 333	212	141 to 333
Temperature(°C)	— Annual	−2.9	−1.6 to −4.1	−2.3	−0.3 to −4.0	−2.5	−0.3 to −4.1
	— January	−22.4	−21.7 to −23.0	−24.4	22.4 to −26.9	−23.7	−21.7 to −26.9
	— July	13.7	12.3 to 16.1	16.6	15.4 to 18.2	12.6	12.3 to 18.2
Growing Degree-days (°C)		779	680 to 923	1172	1013 to 1426	958	680 to 1426
Growing Season (days)		112	83 to 159	138	119 to 158	124	83 to 159
Freeze-free days		132	-	142	124 to 161	140	-

* Statistics compiled for the period 1951 to 1980 from 6 stations (humid) and 7 stations (continental) within the High Boreal region of the Northern Wetlands Study area.

** Based on 2 stations (humid) and 2 stations (continental).

ern Ontario and Manitoba portion (Continental High Boreal) of this wetland region (Map 3.1.1). The western portion is colder in winter (January mean temperature −24.4 versus −22.4°C); has higher summer temperatures (July mean temperature 16.6 vs 13.7°C); a longer growing season (138 vs 101 days); more growing degree-days (1172 vs 779°C) and less total precipitation (545 vs 675 mm) and snowfall (207 vs 222 cm).

Vegetation, Soils, Permafrost and Wildlife

Within the Northern Wetlands Study area, the High Boreal Wetland Region is represented by the Nelson River, Northern Coniferous, Hudson Bay Lowland, Fort George and East James Bay Forest Sections as defined by Rowe (1972, Map 2.8.1). Forests are more widespread and often closed-canopied as compared to Sub-arctic forests. They are reasonably productive with growth rates of at least 2 m^3/ha (Clayton *et al.* 1977). The dominant tree species is black spruce (*Picea mariana*) (Ecoregions Working Group 1989). In the western portion of the study area, subdominant trees include jack pine (*Pinus banksiana*) and white birch (*Betula papyrifera*). White spruce (*Picea glauca*), balsam fir (*Abies balsamea*) and trembling aspen (*Populus tremuloides*) become more common toward the east in Ontario and Québec. Jack pine mixed with black and white spruce typify the driest sites. Understorey vegetation characteristically includes bog cranberry (*Vaccinium myrtilloides*), blueberry (*V. angustifolium*), Labrador tea (*Ledum groenlandicum*), mosses and lichens.

Soil formation is further advanced in the Boreal soils than in the Sub-arctic soils as a consequence of a warmer air temperatures, shorter periods of frozen ground conditions and improved forest growth. Abundant organic material in combination with well-drained, coarse textured materials results in the formation of iron-rich Humo-Ferric Podzols. Fine and medium-textured upland soils commonly display Gray Luvisols and Gray Brown Luvisols. Peat accumulation in wetlands within the High Boreal Wetland Region averages 200 to 300 cm in thickness (Tarnocai 1984) permitting the formation of deep Organic soils. Cryosolic soils are rare, usually confined to organic sites (palsa bogs) in the areas north of Lake Winnipeg and east of James Bay.

Within the Northern Wetlands Study area, the High Boreal Wetland Region forms the southernmost portion of the discontinuous permafrost zone. Permafrost is very sporadic and confined mainly to peatlands (Brown 1968). Permafrost thickness of 15 m was reported by Brown (1967) for two locations near Thompson, Manitoba. Ground temperatures varied between -0.8°C and 0°C at depths of 7.5 and 10 m, respectively.

Typical wildlife species in this wetland region include caribou, black bear, wolf, moose, lynx, beaver, snowshoe hare, spruce grouse, ruffed grouse, sharp-tailed grouse, Canada goose and black duck (Ecoregions Working Group 1989).

3.3.1.2 WETLAND CHARACTERISTICS

Table 3.3.2 summarizes wetland types, soils and other characteristics of the High Boreal Wetland Region. Four major physiographic subdivisions which affect wetland development are identified. The most important areas for wetland development are the glaciolacustrine plains of northern Manitoba and northwestern Ontario (area A), the Hudson Bay Lowland (area D) and the James Bay coast in Québec (area B).

Milder climatic conditions in the High Boreal, than in the Sub-arctic Wetland Regions, results in thicker peat depths (up to twice as deep, on average), a thicker active layer, and a lower frequency of permafrost landforms such as palsa bogs and peat plateau bogs.

The physiography of the Canadian Shield in the High Boreal of the study area is very complex. It includes flat glaciolacustrine plains, drumlinized till plains with glaciolacustrine silts overlying the till between drumlins (formed due to flooding of drumlin fields by glacial lakes) and poorly organized drainage in exposed bedrock uplands. These conditions result in a wide variety of wetland types, distribution and soil conditions (Table 3.3.2).

Wetlands characteristic of the lacustrine plains of the central portion of the High Boreal in Manitoba are described by Mills *et al.* (1978a) as follows:

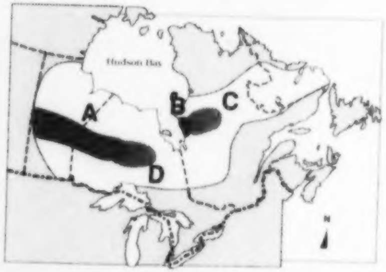
> "Shallow to deep organic deposits cover most of the lacustrine sediments along with the lower slopes of gently sloping till deposits. Bog veneers consisting of thin (less than 1 m) forest peat deposits occupy gently sloping areas of lacustrine veneers and lower slopes of drumlin ridges and till hummocks. Such areas are characterized by discontinuous permafrost... Deep organic deposits occur mainly in level to depressional interdrumlin areas... Such areas consist of peat plateaux characterized by forest peat containing permafrost complexed with minor areas of poorly drained fens comprised of non-frozen fen peat."

TABLE 3.3.2.

Wetland characteristics of the High Boreal Wetland Region.

	CANADIAN SHIELD			HUDSON BAY LOWLAND
	(A)	(B)	(C)	(D)
WETLAND TYPES	Veneer Bog, Palsa Bog, Plateau Bog, Flat Bog, Basin Bog, Horizontal Fen, Northern Ribbed Fen, Stream Swamp	Flat Bog, Horizontal Fen, Freshwater Marsh, Salt Marsh	Flat Bog, Horizontal Fen	Flat Bog, Horizontal Fen, Freshwater Marsh, Salt Marsh
WETLAND DISTRIBUTION (%)	26 to 75	26 to 50	6 to 25	90
MORPHOLOGY/SLOPE	hummocky to flat/gently sloping to level, confined	flat/level	flat/level, confined	flat/level
DEPTH OF PEAT (cm)	200 to 300 (avg) (veneer bogs average 100)	0 to 150	60 to 200	300 to 400 (avg)
DECOMPOSITION	mesic	fibric and mesic	fibric and mesic	mesic
WETLAND SOILS	Fibric Mesisol Mesic Organic Cryosol Peaty Phase Rego Gleysol	Peaty Phase Rego Gleysol Terric Mesisol	Terric Mesisol Fibric Organic Cryosol Typic Mesisol and Fibrisol	Typic Mesisol Fibric Mesisol
SOIL CLIMATE (Temp./Moisture)	Very Cold Subarctic to Cold Cryoboreal/Aquic to Peraquic	Cold Cryoboreal to Very Cold Subarctic/Subaquic	Very Cold Subarctic to Cold Cryoboreal/Perhumid	Cold Cryoboreal to Very Cold Subarctic Peraquic
MEAN ANNUAL GROUND TEMP. (°C)	-0.6 to 2.5	1.5 to 3.3	-	-
ACTIVE LAYER THICKNESS (cm)	60 to 200	-	-	-
SURFACE WATER COVER (%)	25 to 30	5 to 10	10 to 20	-

SOURCES
Clayton *et al.* 1977; Gilbert *et al.* 1985; Manitoba Canada Soil Survey 1986; Mills *et al.* 1978a and 1978b; National Wetlands Working Group 1986; Tarnocai 1984; Veldhuis *et al.* 1979; Young and Judge 1985; Zarnovican and Belair 1979



Mills *et al.* (1978b) describe a basin bog from a nearby area consisting of bedrock knolls and ridges with an average local relief of 20 m as follows:

> "Intervening valley and depression areas between bedrock outcrops are usually occupied by bogs with some local fens. The organic deposits in these areas consist of deep (up to 5 and 6 m) woody forest and sphagnum peat with minor areas of deep fen peat... Gently sloping bog veneers usually underlain by thin till deposits contain only minor amounts of permafrost as compared to similar landforms in more northerly districts."

The Hudson Bay Lowland portion of the High Boreal Wetland Region has mature bog and fen complexes occupying 90 percent of its area. Wetlands are dominated by string bogs (patterned open bogs—Riley 1982), ribbed fens and horizontal fens. As defined by the National Wetlands Working Group (1986), this portion of the region consists of the deeper, more mature interior peatlands exclusive of coastal marshes. Peat depths average 200 to 300 cm over large areas. The proportion of wetland types within this area as identified by Riley (1982) is horizontal fen and ribbed fens about 30 percent, string bogs about 50 percent (including less than 10 percent palsa), and about 10 percent swamp (riparian). The remainder consists of upland features such as raised beach complexes and river levées.

Riley (1982) notes that the frequency of permafrost increases toward the north primarily as 'incipient' palsa features in association with many collapse scars. The close association of palsas and collapse features are typical in the southern portion of the discontinuous permafrost zone reflecting the dynamic nature of peat-permafrost relationships in association with short and medium term climatic conditions (Zoltai and Tarnocai 1975).

Zarnovican and Belair (1979) describe typical wetlands of the James Bay Territory in Québec (area B, Table 3.3.2). Wetlands most typical of the High Boreal along the coast of James Bay (up to 250 m above sea level) are flat (open) bogs and highly minerotrophic horizontal fens, freshwater marshes and salt marshes. The latter two are much more restricted in extent due to generally higher relief along the coast of this portion of James Bay relative to the Hudson Bay Lowland.

On the Shield of the High Boreal in Québec (area C) characteristic wetlands include flat (treed and open) bog, and horizontal fen. Peat thickness is generally between 60 and 200 cm (Zarnovican and Belair 1979) which is thinner than on the Shield in Ontario and Manitoba or in the Hudson Bay Lowland. Palsa bogs also occur but are generally not as common as in other portions of the High Boreal.

Zoltai and Tarnocai (1971) provide a detailed description of a wooded palsa bog located in the southern portion of the High Boreal Wetland Region in Manitoba. They undertook several survey transects which identified specific relationships among vegetation, peat depth, peat type, substrate character and type, permafrost and seasonal frost.

3.3.1.3 WETLAND TYPES

The wetland types most characteristic of the High Boreal Wetland Region within the Northern Wetland Study area are string bogs, basin bogs, flat bogs, veneer bogs, horizontal fens and basin fens. Peat plateau and palsa bogs with dense tree growth occur in fens and within veneer bogs. Collapse scar fens are common in association with peat plateaux and palsa bogs of the High Boreal Wetland Region. Marshes are rare and swamps are restricted to riverine locations and at the margin of bogs (Zoltai *et al.* 1988b).

Flat Bog

Flat bogs are most common in the High Boreal Wetland Region where they occupy large areas in poorly-defined depressions and in lowlands (Zoltai *et al.* 1988b). Physiognomically they are described as low shrub bogs with stunted black spruce (sometimes grading into treed bog) and a dense growth of ericaceous shrubs particularly Labrador tea (*Ledum groenlandicum*), leather-leaf (*Chamaedaphne calyculata*), sheep-laurel (*Kalmia angustifolium*) and the herb *Smilacina trifolia*. The shrubs grow on moss hummocks which are formed from *Sphagnum fuscum*, *S. fallax* and *S. angustifolium* (Zoltai *et al.* 1988b). *Carex oligosperma* is a common sedge which grows in the hollows which are wetter than the hummocks.

The peats of flat bogs generally range from 2 to 4 m in thickness and often consist of 3 layers. The lowest layer is forest peat which includes wood fragments and sedges intermixed; this is overlain by a thick mesic layer and a fibric upper layer from 30 to 60 cm thick consisting of weakly to non-decomposed sphagnum plant remains with leaves and twigs.

Flat bogs in the James Bay area of Québec are characterized by low shrub, graminoid and typical treed bogs. The first two types have at least 100 cm of peat. They occur in depressions and form complexes over large areas on flat-lying terrain. Typical species of shrub bogs include dwarf black spruce, leather-leaf and sphagnum mosses (*Sphagnum fuscum, S. recurvum* and *S. majus*). These bogs have little or no open water at the surface. Graminoid bogs have open water at the surface. They lack a tree stratum but have a minor shrub component of leather-leaf. Characteristic species include sedges (*Scirpus cespitosus*) and the mosses *Sphagnum nemoreum* and *S. majus*. Treed bogs have black spruce between 4 and 10 m in height with a dense growth of Labrador tea and leather-leaf in the shrub layer and several mosses including *Pleurozium schreberi, Sphagnum robustum, S. nemoreum* and *S. fuscum*. Flat bogs of the James Bay area have shallow peat accumulations (50 to 100 cm) with a water table between 30 and 60 cm below the surface (Zarnovican and Belair 1979).

Veneer Bog

Veneer bogs were generally described in Section 3.2.2.3. A veneer bog from the High Boreal Wetland Region at Thompson, Manitoba (55°55' N, 97°43' W) is described in detail by Zoltai *et al*. (1988a). This bog with associated collapse scars formed on lacustrine clays. The bog surface slopes 2.5 m over a distance of 175 m from the upland to a peat plateau bog at the toe of the slope. Black spruce (*Picea mariana*) between 3 and 5 m in height cover about 40 percent of the bog. Other vegetation includes shrubs (*Ledum groenlandicum, Vaccinium myrtilloides* and *V. vitis-idaea*) and herbs such as *Rubus chamaemorus* in the openings and mosses including feathermosses (*Pleurozium schreberi* and *Hylocomium splendens*) and *Sphagnum* spp. The peat thickness of this bog varies from 27 to 70 cm and soils are shallow Organic Cryosols in association with Brunisolic Static Cryosols and Gleyed Brunisols where the peat is shallowest. The active layer is up to 2 m in thickness across most of the bog. At one site on the bog, the active layer thickness varied between 60 and 150 cm over a 5 year period.

String Bog

Sjörs (1959 and 1963) describes typical High Boreal wetlands of the Hudson Bay Lowland from the Attawapiskat River area. He provides a cross-section across a string bog showing relationships among vegetation, bog pools, peat type and peat substrate stratigraphy. He noted the 'remarkable similarity' between the flora of this bog and that of bogs in regions 5,600 km away in northern Europe. This suggests strong ecological controls on wetland flora.

The string bog has a slightly elevated surface with numerous bog pools. Drainage from the bog is gradual without obvious seepage ways or drainage channels. Near the edge of the bog small channel fen serve as drainage ways. These occur at right angles to the bog margin and become narrower away from the bog.

Typical vegetation on the bog is black spruce (*Picea mariana*), Labrador tea (*Ledum groenlandicum*) and leather-leaf (*Chamaedaphne calyculata*). Other common species included sedges (*Carex oligosperma* and *Eriophorum virginicum*), pitcher plant (*Sarracenia purpurea*), bladderwort (*Utricularia cornuta*) and the bog laurels (*Kalmia* spp.).

Sjörs (1959) notes that large bog pools were common and very striking. They occupy 30 to 40 percent of the surface, are a uniform depth of about 1.5 m (5 ft) and are oriented at right angles to the direction of slope. The maximum peat thickness recorded for this site was 400 cm. The peat consisted primarily of sphagnum peat. The peat was more humified toward the bottom with a greater proportion of wood fragments.

Basin Bog

Basin bogs are ombrotrophic wetlands which occupy bedrock depressions in areas with a moderately to strongly broken surface topography. They are especially common within the Boreal Regions of the Canadian Shield. These bogs vary in depth depending, in part, on the depth and configuration of the depression. Substrates beneath the peat may consist of moderately calcareous fine-grained glaciolacustrine sediments, till or bedrock. In some cases the bogs originated as ponds or small lakes, gradually filling-in until the surface is completely vegetated ('terrestrialization'). The peat in these wetlands is minerotrophic consisting of well humified sedge peat and gyttja.

The upper portion of basin bogs are ombrotrophic receiving all nutrients and moisture from direct precipitation and very localized runoff. Zoltai *et al*. (1988b) note that peat depths are greater than 3 m (in fact these can form some of the deepest peat sequences in Mid and Low Boreal areas with between 10 and 15 m of peat). They are commonly treed with mature or stunted black spruce and have a flat surface. Generally the trees become shorter toward the centre of the bog. The bog may grade into swamp or fen at its contact with the surrounding upland, depending on the degree of minerotrophy of local runoff.

The vegetation of basin bogs characteristically consists of black spruce, ericaceous shrubs (*Ledum groenlandicum, Kalmia* spp., *Chamaedaphne calyculata*) and sphagnum mosses. This is reflected in the upper peat layer which is fibric.

Basin Fen

Basin fens are minerotrophic wetlands which occur in bedrock-controlled terrain. As in the case of basin bogs, they are formed from the terrestrialization of formerly open water ponds, small lakes or embayments of large lakes. The primary factor controlling their development as fens is the regular inflow of minerotrophic water (Zoltai *et al.* 1988b). Their surface is usually flat and may be formed of a floating mat held together by roots. Underlying peat is generally well decomposed (mesic to humic) and ranges in thickness from 1 m to more than 6 m.

Physiognomically, basin fens range from treed fen with stunted tamarack (*Larix laricina*) through low shrub and graminoid fen depending on nutrient levels and water table position. Trees and shrubs occupy the slightly higher and drier sites. Characteristic species include shrubs such as *Betula pumila* and *Salix* spp. (especially in thicket swamp margins), sedges (*Carex aquatilis* and *C. lasiocarpa*) and a variety of mosses (Zoltai *et al.* 1988b).

Horizontal Fen

Horizontal fens on glaciomarine sediments of the James Bay coast are characterized by minerotrophic species including low shrubs (*Myrica gale*), sedges (*Carex* spp., *Scirpus hudsonianus*), *Scorpidium scorpioides* (brown moss) and buckbean (*Menyanthes trifoliata*). Zarnovican and Belair (1979) indicate that these wetlands are comparable to low shrub fens (Section 3.2.2.3). Peat thickness averages 100 to 200 cm with the water table at the surface of the peat. Open water in these peatlands averages 5 to 10 percent.

Horizontal fens of upland Shield locations in Québec have sedges (*Carex* spp.), buckbean and sphagnum moss (*Sphagnum pulchrum*) with peat depths generally between 60 and 100 cm (Zarnovican and Belair 1979). The water table is at or above the surface with open water comprising 25 to 50 percent of the peatlands.

3.3.1.4 HIGH BOREAL TOPOSEQUENCE

Figure 3.3.1 is a toposequence illustrating soil-vegetation physiognomy-landform relationships for typical Canadian Shield wetlands in north-central Manitoba. The sequence represents a composite from several cross sections prepared by Mills *et al.* (1978a, b) and Veldhuis *et al.* (1979). Three characteristic landform-wetland terrains are included. From left to right these are a bedrock-controlled basin bog; palsa bogs and riparian swamp formed between drumlins; and a glaciolacustrine plain with veneer bog, palsa bog and plateau bog.

3.3.2 MID BOREAL WETLAND REGION

3.3.2.1 ENVIRONMENTAL SETTING

Physiography

The physiography of the Mid Boreal Wetland Region is the most varied of all wetland regions within the Northern Wetlands Study area. It consists of portions of the Manitoba Plain, Severn Upland, Abitibi Upland, Hudson Bay Lowland and Eastmain Lowland as well as most of the Mistassini Hills Physiographic Divisions (Section 2.5.2). The Kinosheo research site for the Northern Wetlands Study lies within the Hudson Bay Lowland portion of the Mid Boreal Wetland Region.

The Manitoba Plain corresponds to the area of sedimentary bedrock (Interior Platform, Section 2.5.3) west of the Canadian Shield. It has a very gently undulating to flat surface consisting of glaciolacustrine deposits and deep ground moraine (particularly toward the southwest) which completely cover the bedrock. The average elevation of the Plain is about 250 m (Bostock 1970). Much of the area is covered by large lakes including Lakes Winnipeg, Manitoba and Winnipegosis. Widespread fine-grained sediments deposited from glacial Lake Agassiz have resulted in the development of extensive wetlands.

Most of the area of the Severn Upland within the Mid Boreal Wetland Region consists of weakly to moderately undulating, bedrock-controlled topography. The western portion in Manitoba and northwestern Ontario has exposed bedrock and localized areas of shallow sandy to silty ground moraine (Wickware and Rubec 1988). Clays and silts deposited in glacial Lake Agassiz occur as discontinuous thin deposits in most valleys and in bedrock depressions. The area around Dryden is dominated by a weakly undulating varved clay plain. To the east, the terrain becomes undulating to rolling with shallow to moderately deep sandy to coarse loamy textured moraine. Exposed bedrock knolls are frequent.

The Abitibi Upland grades from the rolling bedrock-controlled terrain of the Severn Upland in the west to the weakly broken to flat lying glaciolacustrine clay plain of northeastern Ontario and western Québec. Fine-grained sediments of this plain were deposited from glacial Lake Barlow-Ojibway and, in some areas, reworked into clay moraine during late glacial readvances from the north. Coarse sandy glaciofluvial outwash deposits are particularly common in western portions of the plain.

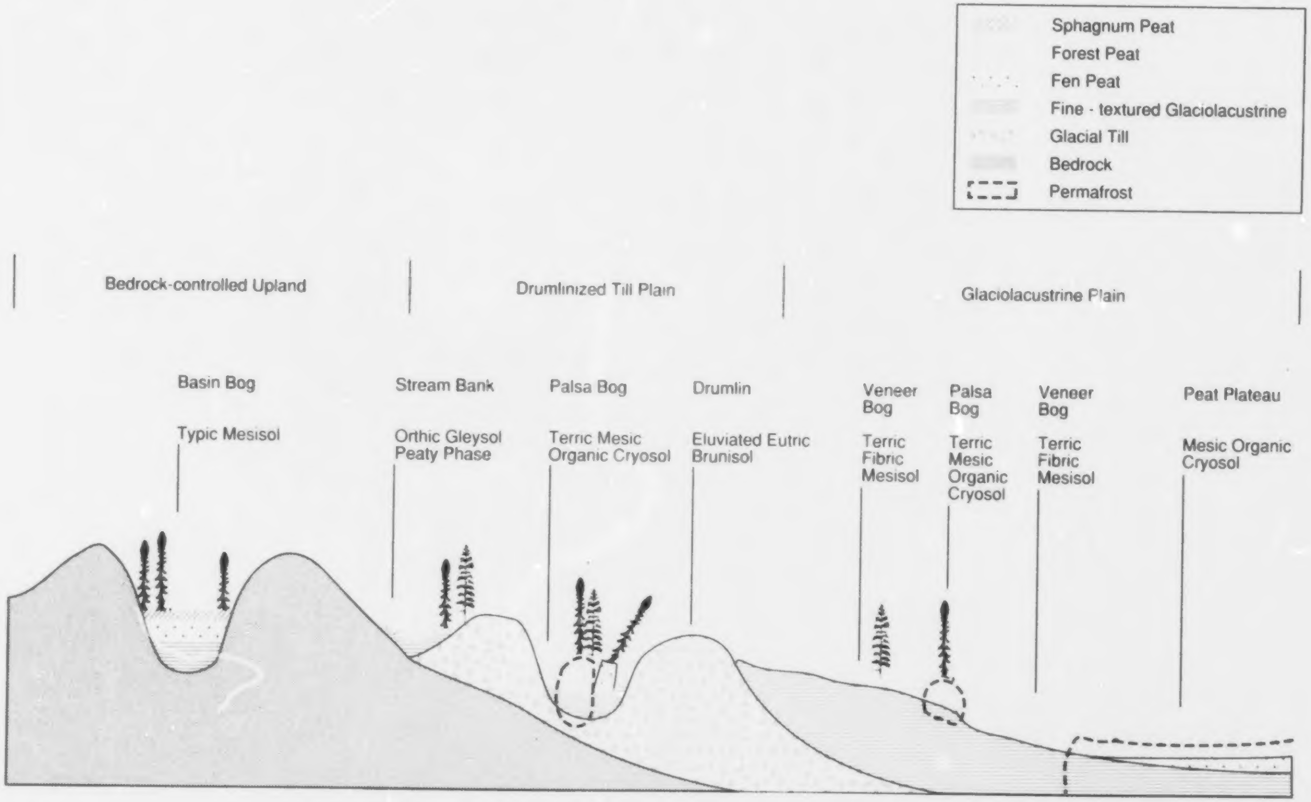


FIGURE 3.3.1

Toposequence for the High Boreal Wetland Region illustrating relationships among soils, vegetation physiognomy and landform for bedrock-controlled upland, drumlinized till plain and glaciolacustrine plain in north-central Manitoba (modified from Mills *et al*. 1978a, 1978b and Veldhuis *et al*. 1979).

Immediately north of Lake Superior, in the westernmost portion of the Abitibi Upland, is one of the most rugged areas of the Northern Wetlands Study area outside of Labrador. This area is referred to as the Superior Highlands (Wickware and Rubec 1988). It is characterized by strongly to moderately broken topography with shallow sandy to loamy morainal deposits. Numerous granitic rock outcrops and abrupt cliff faces occur in this area. Deeply incised rivers draining into Lake Superior have thick sequences of sandy outwash deposits overlain with varved lacustrine clays and silts.

In Québec, to the north of the clay plain, is the Eastmain Lowland. Near James Bay it is a glaciomarine plain of level clays with coarse beach deposits. Eastward it grades into a weakly broken plain consisting of glaciolacustrine clays and silts overlying bedrock and, in the extreme east near Lac Mistassini, it consists of a bedrock-controlled moderately broken plateau covered with shallow to moderately thick ground moraine (Gilbert *et al.* 1985). Overall the surface slopes westward with drainage toward James Bay. The highest elevations in this wetland region are in the Mistassini Hills which commonly stand 760 m above Lac Mistassini and reach up to 1060 m above sea level (Bostock 1970). The lake occupies a series of long narrow valleys between northeast-southwest trending hills and ridges.

Climate

In the more southerly Mid Boreal Wetland Region, the mean annual temperature exceeds 0.0°C (Table 3.3.3). The growing season is longer and there is a significant increase in growing degree-days (1410 versus 958°C) when compared to the High Boreal.

This wetland region also has a significant contrast between its western and eastern sections. In the Northern Wetland Study area, the Continental Mid Boreal begins in the vicinity of Sioux Lookout, Ontario and stretches to the border of Manitoba (Map 3.1.1). The Humid Mid Boreal, in the east, experiences less bright sunshine (1807 versus 2248 hours); more total precipitation and snowfall (841 versus 548 mm and 269 versus 160 cm, respectively); a cooler mean annual temperature (0.2 versus 0.8°C) and less severe winter temperatures (−18.9 versus −20.9°C).

Vegetation, Soils, Permafrost and Wildlife

The Mid Boreal Wetland Region within the Northern Wetlands Study area consists of the southern portion of the Northern Coniferous Forest Section (Rowe 1972), as well as the Manitoba Lowlands, Central Plateau, Nipigon and Northern Clay Forest Sections of the Boreal Forest Region (Section 2.8). Black spruce (*Picea mariana*) occurs but does not form the dominant tree species within the extensive forests of this region. White spruce (*P. glauca*), trembling aspen (*Populus tremuloides*) and balsam fir (*Abies balsamea*) are the most common trees on upland sites of the Mid Boreal Wetland Region (Ecoregions Working Group 1989). In the west, such as in the Manitoba Lowlands Forest Section, upland forests are predominantly deciduous with trembling aspen and balsam poplar (*Populus balsamifera*). These deciduous forests are characterized by diverse understorey vegetation (Ecoregions Working Group 1989).

TABLE 3.3.3

Mid Boreal Wetland Region climate statistics*

		WETLAND SUBREGIONS					
		HUMID		CONTINENTAL		COMBINED	
CLIMATE ELEMENT		Mean	Range	Mean	Range	Mean	Range
Bright Sunshine (hrs)**		1807	1687 to 1983	2248	2147 to 2391	2028	1687 to 2391
Precipitation (mm)	— Annual	841	738 to 950	548	443 to 713	701	443 to 950
Snowfall (cm)	— Annual	269	184 to 341	160	109 to 230	217	109 to 341
Temperature (°C)	— Annual	0.2	−1.4 to 2.0	0.8	-0.7 to 2.2	0.5	−1.4 to 2.2
	— January	−18.9	−16.3 to −22.3	−20.6	−19.0 to −22.7	−19.7	−16.3 to −22.7
	— July	16.7	16.1 to 17.7	18.4	17.7 to 19.7	17.5	16.1 to 19.7
Growing Degree-days (°C)		1300	1130 to 1502	1530	1331 to 1757	1450	1130 to 1757
Growing Season (days)		131	112 to 152	152	138 to 163	141	112 to 163
Freeze-free days		147	126 to 163	163	156 to 178	155	126 to 178

* Statistics compiled for the period 1951 to 1980 from 12 stations (humid) and 11 stations (continental) within the Mid Boreal region of the Northern Wetlands Study area.

** Based on 4 stations (humid) and 4 stations (continental).

Spruce and fir coniferous forests with a moss and lichen understorey dominate in the east. Jack pine (*Pinus banksiana*) is common on the driest sites in central and eastern portions of the region, often in combination with white birch (*Betula papyrifera*) and black spruce.

Soils are similar to those of the High Boreal Wetland Region although the milder climate in the Mid Boreal permits deeper profile development in Humo-Ferric Podzols and Gray Luvisols. Organic and peaty phase Gleysols are common in the imperfectly to poorly drained portions of the glaciolacustrine deposits. Peat accumulations are greater, on average, than in the High Boreal. The Mid and Low Boreal peatlands of the Northern Wetlands Study area have the deepest peats in Canada (on average), outside the Maritimes. Average peat depth within these wetland regions ranges from 300 to 400 cm (Tarnocai 1984). With the exception of the areas immediately southwest and east of James Bay, the Mid Boreal Wetland Region is entirely south of the southernmost extent of permafrost (Map 2.6.3).

Wildlife species common to this wetland region within the Northern Wetlands Study area include moose, black bear, beaver, muskrat, timber wolf, snowshoe hare, caribou (in central and eastern portions), lynx, coyote, sharp-tailed grouse, black duck, wood duck, hooded merganser (in the east) and pileated woodpecker (Ecoregions Working Group 1989).

3.3.2.2 WETLAND CHARACTERISTICS

Table 3.3.4 provides a summary of the dominant characteristics for wetlands, wetland soils and other aspects of the Mid Boreal Wetland Region. The Region is separated into five subareas based on physiographic controls on wetland development. The most important subareas for wetland development are the Manitoba Plain (area A, Table 3.3.4), the Hudson Bay Lowland (area E) and the glaciolacustrine plain of northeastern Ontario and western Québec (the 'Clay Plain', area D)).

Wetlands dominate the Manitoba Plain, particularly on the low lying flats surrounding Lake Winnipeg where they are virtually continuous. Wetlands on this plain are characterized by flat and domed bogs with broad areas of horizontal fen (Manitoba-Canada Soil Survey 1986). Peat depths average 400 cm of dominantly mesic peat. Shallow peat marshes occupy large areas of lake shoreline. These wetlands have the greatest coverage of open water which reaches up to 60 percent of the surface area. The Rice River Land District of Dutchak *et al.* (1978, also Woo *et al.* 1977) lies along the east-central shore of Lake Winnipeg. They describe this Land District as follows:

> "...a dominantly poorly drained organic plain broken by occasional rock outcrops... The organic terrain is dominated by large patterned fens [ribbed fen] with smaller areas of flat bog and raised bog plateau [domed bog]... Relief in this district is usually less than 3 m. Although the organic terrain is extensive the average depth of the deposits is more shallow than that encountered in the two land districts to the east. The dominant organic materials are Mesic Fen Peat, seldom exceeding 2 m in depth. They are underlain by calcareous lacustrine sediments ranging in texture from dominantly clay to fine sandy loam... The Rice River District is characterized by few, small lakes, most of which have smooth, regular organic shorelines. Several rivers and streams flow across the district; aside from these, surface drainage is not evident into Lake Winnipeg."

Thie (1974) discusses the distribution and thawing characteristics of permafrost in the Mid Boreal along the northwestern shore of Lake Winnipeg.

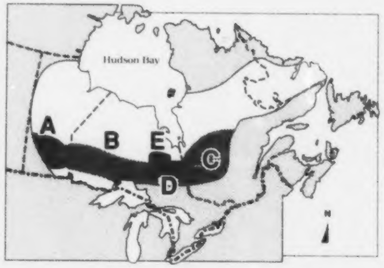
The wetlands of the Hudson Bay Lowland are highly varied reflecting the complex nature of the Mid Boreal in this region. This portion of the Lowland consists of flat glaciomarine plains, large alluvial basins along the major rivers (eg., Moose and Albany Rivers) and a raised till plateau (Pala and Weischet 1982). It is floristically very rich with elements of more temperate areas (Riley 1982). Wetlands include deciduous swamps, conifer swamps, cedar fens, small incipient palsas, horizontal fens (mostly graminoid and treed), flat bogs (mostly treed) and string bogs (open) (Riley 1982, Jeglum and Cowell 1982). In the Kinosheo area, average peat depths of all wetlands range between 110 cm and 280 cm (Jeglum and Cowell 1982) with peat in excess of 400 cm in many areas south of 50°30' N (Riley 1982). Riley (1982) notes that interior bogs have more frequent seasonal droughts than elsewhere in the Lowland. Toward the Canadian Shield boundary of the Lowland, wetlands become less continuous with bedrock knolls appearing in increasing abundance. The proportion of upland terrain is highest in the Mid Boreal portion of the Lowland reaching up to 40 percent in places (Riley 1982). This is due to the abundance of large raised beach ridges and former coastal promontories in combination with the relatively high central till plain. The till plain has generally shallow peats, given its distance inland from the coast, and is characterized by the presence of large lakes, such as Kinosheo, with mineral soil bottoms and marsh edges. Flat treed bogs

TABLE 3.3.4

Wetland characteristics of the Mid Boreal Wetland Region

	MANITOBA PLAIN	CANADIAN SHIELD			HUDSON BAY LOWLAND
	(A)	Ground Moraine / Bedrock (B)	(C)	Glaciolacustrine (D)	(E)
WETLAND TYPES	Flat Bog, Domed Bog, Northern Ribbed Fen, Horizontal Fen, Lake Marsh	Basin Bog, Flat Bog, Veneer Bog, Channel Fen, Basin Fen	Basin Bog, String Bog, Flat Bog, Veneer Bog, Horizontal Fen, Basin Fen	Domed Bog, Flat Bog, Conifer Swamp,Stream Fen	Flat Bog, Domed Bog, Horizontal Fen, Conifer Swamp
WETLAND DISTRIBUTION (%)	26 to 100	6 to 50	6 to 25	51 to 75	60 to 85
MORPHOLOGY/SLOPE	flat/level	flat/level to gently sloping, confined	flat/level to gently sloping, confined	domed, flat/gently sloping, confined	flat, domed/level
DEPTH OF PEAT (cm)	400 (average)	400 (average)	300 to 400 (average)	500 (average)	100 to >400
DECOMPOSITION	fibric and mesic	mesic and humic	mesic	mesic and humic	mesic
WETLAND SOILS	Humic Gleysol Terric Mesisol Mesic Fibrisol	Peaty Phase Rego Gleysol Typic Mesisol & Humisol Mesic Fibrisol	Typic Mesisol and Fibrisol Terric Mesisol	Peaty Phase Rego Gleysol Typic Mesisol & Humisol	Typic Mesisol Fibric Mesisol
SOIL CLIMATE (Temp./Moisture)	Cold to Moderately Cold Cryoboreal/Subhumid to Humid	Mod. Cold Cryoboreal/ Perhumid	Cold Cryoboreal/Perhumid	Mod. Cold Cryoboreal/ Aquic	Moderately Cold Cryoboreal/Aquic
MEAN ANNUAL GROUND TEMPERATURE (°C)	5.2 to 6.4	2.5 to 4.5	-	5.2 to 6.2	-
SURFACE WATER COVER (%)	50 to 60	-	0 to 10 (west) 10 to 20 (east)	0 to 10	10

SOURCES:
Clayton *et al.* 1977; Dutchak *et al.* 1978; Gilbert *et al.* 1985; Jeglum and Cowell 1982; Manitoba-Canada Soil Survey 1986; National Wetlands Working Group 1986; Raveling and Lumsden 1977; Riley 1982; Wickware and Rubec 1988; Woo *et al.* 1977; Young and Judge 1985; Zarnovican and Belair 1979.



occupy approximately 20 percent, flat and string open bogs about 15 percent, horizontal fen about 10 percent and swamp about 20 percent of the Mid Boreal Wetland Region in the Hudson Bay Lowland (Riley 1982).

Raveling and Lumsden (1977) provide a detailed description of wetlands within a 412 km^2 area surrounding Kinosheo Lake (formerly known as Kinoje Lake). They describe the wetland terrain, map areas of bog and fen, identify percent cover of 10 physiognomically classified wetlands. Raveling and Lumsden (1977) also provide data on precipitation, temperature and water levels collected at Kinosheo Lake. Cowell *et al.* (1978) identify the occurrence of permafrost and seasonal frost in specific peatland types in the bogs and fens surrounding Kinosheo Lake. They provide descriptions of the wetland types in which frost was found along with depth to and thickness of ice layers, depth of peat and depth to the groundwater surface.

The Clay Plain, located on the Canadian Shield south of the Hudson Bay Lowland (area D, Table 3.3.4), has a wetland cover of up to 75 percent. Domed and flat bogs along with conifer swamps dominate the wetlands of this area. Peat depths are variable but average 500 cm with some domed bogs and basin fens with depths in excess of 600 cm. The warmer climatic conditions and longer ice-free period relative to more northerly wetland regions has allowed the accumulation of deep peats with more humified lower strata.

The physiognomic wetland classification developed by Jeglum *et al.* (1974) was based largely on examples taken from the clay belt. Jones *et al.* (1983) define 14 'Operational Groups' for the clay belt. Operational Groups are areas of mature forest defined on the basis of vegetation and soil conditions in relation to forest management requirements. Two of the Groups are mineral soil wetlands dominated by peaty phase Gleysols (feathermoss-sphagnum and conifer-herb/moss rich Groups) and four are organic soil wetlands (ledum; alnus-herb poor; alnus-herb rich; and chamaedaphne Groups). Kalela (1962) describes the major portion of the clay belt as represented by minerotrophic swamp forests (conifer swamps) with well-grown, closed canopied black spruce. Smaller areas are identified as thick ombrotrophic peat beds (domed bogs). The richer portions of the conifer swamps may also have balsam poplar, white spruce, white cedar and/or tamarack.

Peatlands defined by Stanek (1977) include 3 types of open bog (mostly domed bog), 2 treed bog types (flat bog), 2 open fen types (horizontal fen), a meadow marsh type, a thicket swamp type and 6 varieties of conifer swamp. Swamp peatlands represented 43 percent of the stands sampled in this study.

Dai *et al.* (1973) reported detailed seasonal water level measurements for 5 physiognomic wetland types associated with a large domed bog complex in the clay belt near Cochrane, Ontario. Precipitation measurement and water level recording was undertaken during the summer of 1967. A sloping bog which paludified upland forested terrain at the northern edge of the clay belt in Ontario is described by Terasmae (1970). He describes the peat stratigraphy, pollen assemblage, peat/substrate relationships; provides detailed cross sections showing peat depth (up to 3 m); and discusses the post glacial development of the peatland.

3.3.2.3 WETLAND TYPES

The most characteristic wetland types of the Mid Boreal Wetland Region are domed bogs, flat bogs, basin bogs, conifer swamp, horizontal fen, ribbed fens and basin fens. Shoreline marshes develop along lakes with mineral substrates throughout this wetland region (Zoltai *et al.* 1988b). Data summarizing depth to water table, peat depth, groundwater pH and calcium concentration, and peat humification is provided in Table 3.3.5 for several wetland types in the Kinosheo Lake area of the Hudson Bay Lowland. This portion of the Mid Boreal Wetland Region is also shown in Image 3.2.2 in association with the toposequence discussion for the Low Sub-arctic (Section 3.2.2.4)

Domed Bog

Domed bogs are ombrotrophic wetlands. They are large circular to oval bog complexes which are elevated above the surface of the surrounding fen or swamp. The centre of the bog is high and the surface slopes outward in all directions. The elevation of the surface is created by rapid growth of the mound-forming sphagnum mosses following the establishment of ombrotrophic conditions. The wetland surface is very hummocky and upper peats generally consist of thick sequences of fibric sphagnum materials overlying mesic to humic fen peats. Physiognomically they include low shrub, graminoid and sphagnum bog types as defined by Jeglum *et al.* (1974) for the clay belt (also Jeglum and Cowell 1982 for the Kinosheo area).

The water table in these bogs is also elevated above the surface of the surrounding wetland but is below the surface of the bog (13 to 25 cm below, on average) (Jeglum and Cowell 1982). Bog pools are often present. The pools are either distributed randomly or appear as crescent-shaped pools with their long axis oriented along the surface contour (Zoltai *et al.* 1988b).

TABLE 3.3.5

Means and ranges of depth to water table, peat depth, peat humification, and groundwater pH and calcium concentration for physiognomic wetland types in the Kinosheo Lake area.

	Marsh	Thicket Swamp	Conifer Swamp	Fen Pool Moss Mat	Graminoid Fen	Low Shrub Fen	Tamarack Fen	Cedar Fen	Open Bog*	Low Shrub Bog	Treed Bog
Number of Stands	2	2	4	4	9	6	5	4	4	8	4
DEPTH OF WATER (cm) Below (+) Above (-) Surface											
—from highs	6	0**	42	10	3	23	26	32	18	40	54
—from lows	-4	-1	14	0	-4	4	9	3	6	9	26
—mean	1	-1	28	5	-1	14	18	17	13	25	40
PEAT DEPTH (m)											
(mean)	1.1	1.8	1.2	2.1	1.7	1.1	1.3	1.1	2.2	2.6	2.2
(range)	0.3-1.7	0.7-2.9	0.7-1.8	1.2-2.6	0.7-3.5	0.7-2.2	1.1-1.7	0.9-1.3	2.0-2.4	2.2-3.0	1.4-2.8
GROUNDWATER											
—pH (mean)	5.6	6.0	5.5	5.4	5.5	5.2	5.9	5.4	3.9	3.6	3.5
(range)	5.5-5.7	5.5-6.4	3.8-6.6	3.9-7.3	3.6-6.8	3.8-6.8	5.7-6.0	4.2-6.0	3.6-4.3	3.3-3.9	3.1-3.9
—calcium (mg/L)											
(mean)	6.7(2)	8.7(1)	18.2(3)	7.1(4)	12.4(7)	23.9(2)	7.1(3)	4.7(4)	0.7(4)	0.7(6)	0.9(3)
(range)	5.2-8.2	8.7	3.6-35.0	4.3-14.0	2.0-56.0	4.7-43.0	6.5-7.8	3.2-6.4	0.5-1.3	0.5-0.8	0.5-1.1
PEAT (0-20cm)											
—humification	5.2	4.2	4.4	1.8	2.6	2.9	2.7	3.4	2.0	2.3	2.2
—pH, moist-peat											
(mean)	5.2	5.5	5.2	4.8	5.2	4.9	5.7	5.0	3.4	3.2	2.8
(range)	4.8-5.6	5.4-5.6	3.1-6.7	3.2-6.4	3.5-6.7	3.4-7.0	5.3-6.3	3.8-6.0	3.3-3.6	2.8-3.4	2.6-3.3
PEAT (20-40cm)											
—humification	7.3	7.2	6.6	3.1	4.8	4.2	4.0	5.8	3.6	4.3	3.8
—pH, moist-peat											
(mean)	5.6	5.8	5.4	5.0	5.3	5.2	5.8	5.2	3.5	3.3	3.0
(range)	5.6-5.6	5.7-6.0	4.0-6.2	3.5-6.2	4.4-5.8	3.6-6.8	4.8-6.2	4.3-6.0	3.2-3.6	2.9-3.8	2.6-3.2

SOURCE: Jeglum and Cowell 1982

* Includes Graminoid and Sphagnum Bogs.

** Measure for one stand only.

Characteristic species include shrub-like black spruce ('krummholz'), leather-leaf (*Chamadaphne calyculata*), sheep-laurel (*Kalmia angustifolia*), Labrador tea (*Ledum groenlandicum*), bog rosemary (*Andromeda glaucophylla*), bog cranberry (*Oxycoccus microcarpus*), sedges (*Carex oligosperma*), lichens (*Cladonia* spp.) and sphagnum mosses (*S. rubellum*, *S. nemoreum*, *S. pulchrum*, *S. magellanicum*, *S. fuscum*). The low shrub bog physiognomic type had the thickest mean peat depth at 2.6 m in the Kinosheo Lake area (Jeglum and Cowell 1982). Elsewhere they typically exceed 3 m in thickness (Zoltai *et al.* 1988b).

Zoltai *et al.* (1988b) provide detailed descriptions of two domed bogs from the clay belt area of Ontario.

Marsh

Shoreline marshes in the Kinosheo Lake area have been described by Jeglum and Cowell (1982). The marshes consist of relatively tall graminoids in zones or patches along rivers and lakes. They are influenced by widely fluctuating water levels with periodic or prolonged periods of flooding by minerotrophic waters. Peat is generally absent or thin with emergents being rooted directly in the mineral soil. Common species include beaked sedge (*Carex rostrata*), marsh spike-rush (*Eleocharis palustris*) and marsh cinquefoil (*Potentilla palustris*).

Flat Bog

Although most common in the High Boreal Wetland Region, flat bogs also occur in the Mid Boreal Wetland Region. A flat bog located on the Manitoba Plain adjacent to Lake Winnipeg has been described by Zoltai *et al.* (1988b). This is the treed bog physiognomic type with black spruce less than 5 m in height covering about 70 percent of the bog. The peat thickness was 469 cm consisting predominantly of *Sphagnum fuscum* remains (325 cm). Below this was a mixed *Sphagnum-Menyanthes* peat (60 cm) overlying fen peat. The upper two-thirds of the peat formed under ombrotrophic conditions as shown by chemical analyses. Zoltai *et al*. (1988b) interpret the development of the wetland as originating under minerotrophic conditions, first as a wet meadow marsh followed by open fen, then becoming ombrotrophic with typical bog vegetation. Radiocarbon dating of basal peats indicate that peat deposition began about 4,300 years ago.

Horizontal Fen

These fens have flat, featureless surfaces with water tables at or near the peat surface. They are minerotrophic and consist of graminoid, low shrub and tamarack treed fen (Section 3.2.2.3). Within the Mid Boreal Wetland Region of the Northern Wetlands Study area they are best developed adjacent to Lake Winnipeg in the Manitoba Plain and on the broad alluvial plains of the Moose River in the Hudson Bay Lowland. Localized areas of these fens occur throughout the Mid Boreal. Minerotrophic conditions are maintained by groundwater which receives nutrients either from surrounding upland terrain or via contact with base-rich substrates as in the case of the large unconfined peatlands of the Hudson Bay Lowland.

In the Kinosheo area of the Hudson Bay Lowland, restricted areas of horizontal fen are represented primarily by graminoid fen (Jeglum and Cowell 1982). They occur mostly along drainageways and as floating mats within larger bog and fen complexes. The water level is above the surface (average 1 cm above) and the vegetation is dominated by sedges (*Carex* spp.), horsetail (*Equisetum fluviatile*), buck-bean (*Menyanthes trifoliata*) and moss (*Drepanocladus aduncus*).

The poorest graminoid fens have *Sphagnum* spp. as the dominant moss. Peats are almost entirely sedge peat and average 170 cm in depth.

In shrub fens, common shrub species are *Betula pumila* and *Rhamnus alnifolia* and tamarack (*Larix laricina*) is the main tree species in treed fens. Herbs such as *Scirpus cespitosus, S. hudsonianus* and *Equisetum fluviatile* are common in both shrub and treed fens (Zoltai *et al*. 1988b). *Sphagnum* spp. are common to these fens in the form of low hummocks and wet carpets. Other mosses, low shrubs, sedges and herbs are also present (Jeglum and Cowell 1982, Sims *et al*. 1982b, Zoltai *et al*. 1988b).

In some horizontal fens, alternating areas of wet and relatively drier conditions result in a pattern of lineations visible from the air (Zoltai *et al*. 1988b). The lineations are elongated in the direction of flow. Ombrotrophic black spruce islands may also occur in these fens. The islands form relatively higher portions of the fen with the living vegetation isolated from the minerotrophic groundwater of the fen. In these cases, long tails may form downstream of the island as a result of deflection of the groundwater flow by the island.

Minerotrophic conditions are quite varied in fens and range from conditions of rich fen through to poor fen which approaches ombrotrophic conditions. Moore and Bellamy (1974) indicate the rich fen/poor fen limit occurs at a calcium concentration of 18 mg/L and the lower limit of minerotrophy is at 1 mg/L. Based on calcium content in groundwater, low shrub fens in the Kinosheo area were the most minerotrophic (average calcium concentration of 23.9 mg/L) followed by graminoid fens (average 12.4 mg/L) and treed fens (average 4.7 to 7.1 mg/L) (Jeglum and Cowell 1982). In contrast, conifer swamps averaged 18.2 mg/L and bogs, which receive all nutrients from the atmosphere, averaged between 0.7 and 0.9 mg/L.

Ribbed Fen

Boreal ribbed fens are minerotrophic wetlands characterized by the development of narrow (1 to 5 m wide), low (5 to 75 cm high) peat ridges known as 'strings' (Zoltai *et al*. 1988b). They are particularly common in the boreal wetland regions to the west of the Northern Wetland Study area. Within the study area, ribbed fens occur in the High and Mid Boreal Wetland Regions in areas of large relatively unconfined peatlands such as on the glaciolacustrine deposits of Lake Agassiz in Manitoba and on the glaciomarine sediments of the Hudson Bay Lowland. The origin of ribbed fens is not completely understood. Zoltai *et al*. (1988b) review several concepts and identify common parameters.

Strings of ribbed fens are oriented perpendicular to the direction of flow and may form elongated polygonal patterns (often referred to as 'patterned fens') as they meander and branch across the wetland. The patterning tends to become more pronounced the gentler the slope and, hence, these fens are common in the Hudson Bay Lowland. The intervening wet moss areas are called 'flarks' (Moore and Bellamy 1970). According to Zoltai *et al*. (1988b) the strings act as small dams impeding the drainage which raises the water level in the upstream flark. The water level in each flark decreases slightly in the downslope direction.

The vegetation of the flarks is markedly different from the strings. Relatively drier conditions on the strings usually result in the development of low shrub or treed fen types (Jeglum and Cowell 1982). Trees are usually tamarack, however, eastern white cedar (*Thuja occidentalis*) becomes more prominent in ribbed fens of the southern Mid Boreal Wetland Region. Shrubs are commonly willow (*Salix* spp.), *Betula pumila* and *Andromeda glaucophylla*. The wet flarks ('fen pool moss mats' of Jeglum and Cowell 1982) are dominated by mosses such as *Scorpidium scorpioides* and *Drepanocladus* spp. along with *Carex* spp., *Scirpus* spp., *Menyanthes trifoliata* and *Utricularia* spp. (the bladder-worts). The moss mats are typically very wet and may form a floating surface. In the Kinosheo Lake area, the water table in fen moss mats averages 5 cm above the moss surface.

Peats in these fens are typically mesic. Thin fibric upper layers may occur in the strings especially in poor fens which are dominated by *Sphagnum* spp. Peat thickness is generally greater than 1 m (Zoltai *et al.* 1988b).

Conifer Swamp

Conifer swamps are minerotrophic wetlands which range from mineral soil conditions (i.e., less than 40 cm of peat) to peatlands with up to 2 m of peat, although they are most commonly a peatland form. In the Hudson Bay Lowland, conifer swamps are most common along streams and rivers where they form on the top of low levées or on the backslope of high levées between upland and bog. In these situations they are periodically flooded by minerotrophic stream waters. In the clay belt of Ontario and Québec, conifer swamps form large peatland areas and may support productive black spruce forests.

Jeglum and Cowell (1982) describe the conifer swamp typical of the Kinosheo Lake area of the Hudson Bay Lowland. Conifer swamps are wetland forests with moderately closed canopies. Black spruce is the dominant tree species although white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*) occur and occasionally form the dominant tree. Forests in conifer swamps range from very productive to marginally productive. The ground layer is composed predominantly of non-sphagnum mosses such as the feathermosses (*Hylocomium splendens* and *Pleurozium schreberi*) and the common fern moss (*Thuidium delicatulum*).

These wetlands are characterized by a very uneven surface consisting of pits and channels formed largely by fallen trees. The water table is exposed in the pits and the average depth to water is 28 cm. Peat depth is quite variable in these sites, ranging between 70 and 180 cm with a mean of 120 cm (Table 3.3.5).

Jeglum and Cowell (1982) note that conifer swamp is the wetland type forming the 'black spruce islands' (c.f., Sjörs 1961, 1963) in this portion of the Lowland. In the Kinosheo Lake area, these islands form within open fen and occupy elevated portions of the mineral soil either on the higher portions of raised beach ridges or, more likely, on wave-modified glacial features such as drumlins (Cowell *et al.* 1978). Black spruce islands in the High Boreal and Low Sub-arctic occurring in large horizontal fens and with ombrotrophic bog 'tails' in the direction of groundwater flow are mostly treed bog assemblages.

3.3.2.4 MID BOREAL TOPOSEQUENCE

The toposequence diagram in Figure 3.3.2 illustrates the relationship among soils, landform and physiognomic wetland type for the clay belt area of the Mid Boreal. Upland terrain (far right) grades downslope into conifer swamp (3 physiognomic types as identified by Jeglum *et al.* 1974), flat bog and, on the lowest portion of the landscape, domed bog. The soils range from Podzols on coarse-textured materials and Luvisols on clays and silts of the upland sites, gleyed Podzols or Luvisols on mid to lower slope positions (not shown) through Gleysols on lower slopes to Organic soils at the base of the slope. The peat blanket may reach 6 m or more in depressions.

3.3.3 LOW BOREAL WETLAND REGION

3.3.3.1 ENVIRONMENTAL SETTING

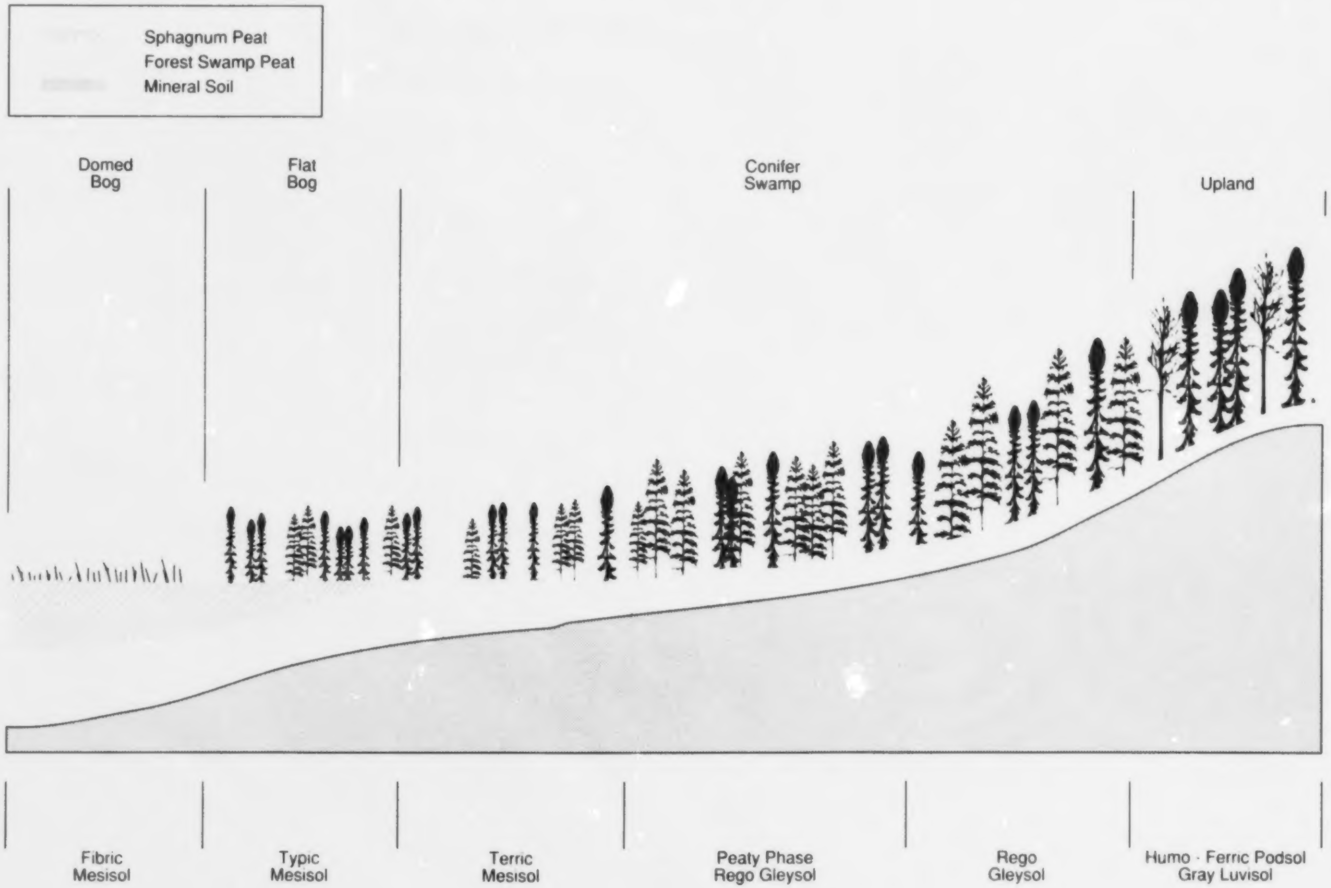
Physiography

The Low Boreal Wetland Region lies along the southern boundary of the Northern Wetlands Study area in Ontario and western Québec (Map 3.1.1). It is best expressed in northwestern Ontario where it comprises the southernmost portion of the Severn Upland Physiographic Division and all of the Port Arthur Hills Physiographic Division (Section 2.5.2). In western Québec, it forms the eastern portion of the Abitibi Upland.

The maximum elevations in this wetland region are about 460 m which is the elevation of the drainage divide between the Great Lakes-St. Lawrence and Hudson Bay Drainage Basins as well as the highest elevation of the ridges and promontories of the northwest shore of Lake Superior (Port Arthur Hills, Bostock 1970). The geology of the Port Arthur Hills is quite distinct from the typical Canadian Shield (Section 2.5.3). Flat lying sedimentary rocks capped with resistant

FIGURE 3.3.2

Toposequence for the Mid Boreal Wetland Region illustrating relationships among soils, wetland physiognomy and landform for the clay belt glaciolacustrine plain in northeastern Ontario and western Québec (modified from Jeglum *et al*. 1982).



layers of basaltic rocks (igneous 'sills') form a mesa-like topography with abrupt cliffs and escarpments common in the area around Thunder Bay, Ontario.

The western extension of the Low Boreal Wetland Region, in southeastern Manitoba, is characterized by a flat to gently undulating plain which slopes toward the west. This plain is predominantly composed of glaciolacustrine clays of glacial Lake Agassiz along with fine-grained alluvial deposits. As a result, extensive wetlands have formed. This area has the greatest distribution of wetlands in the Low Boreal within the Northern Wetlands Study area.

To the east and north of Kenora, the terrain becomes more typical of the Shield with widespread exposed bedrock. The topography is weakly to moderately broken with shallow morainal material consisting of loamy to silty sands mixed with large boulders (Wickware and Rubec 1988). To the southeast of the Lake of the Woods are flat to weakly broken highly calcareous clay plains representing glacial Lake Agassiz deposits.

The eastern half of this wetland region in northwestern Ontario ranges from moderately broken Shield terrain to the strongly broken topography of the mesas around Thunder Bay. Surficial materials are generally shallow sandy morainal deposits in upland areas with deep silty-clay glaciolacustrine deposits in low lying areas along the western edge of Lake Superior. These were deposited by a postglacial lake which occupied the Superior basin. West of Lake Nipigon and northwest of Thunder Bay are extensive plains consisting of outwash sands and gravels broken by occasional bedrock knolls. Wind erosion has resulted in the formation of large dune fields on these plains (Wickware and Rubec 1988).

Climate

In the Northern Wetlands Study area, the Low Boreal Wetland Region occurs in Québec and also extends from the northwest shores of Lake Superior to just inside the Manitoba border. The Arctic airstream dominates for six months or less in the Low Boreal Wetland Region (Bryson and Hare 1974). Frequent incursions of Tropical and Pacific air masses also affect the region. Climate statistics are summarized in Table 3.3.6.

Typically, there is a contrast between the climate in the east and the west. The region northwest of Lake Superior (represented by the Kenora climate station, Section 2.3.2) experiences a continental climate. For example, precipitation in winter is low (snowfall of 117 to 238 cm) while summer precipitation is higher. Total precipitation is lower in the west than in Québec where total precipitation and snowfall reach maximums of 1000 mm and 352 cm, respectively for Chibougamau. A snowbelt, however, exists on the northeastern shore of Lake Superior just outside the Northern Wetlands Study area.

In the Québec portion, the mean July temperature is cooler which contributes to a lower mean annual temperature. Growing degree-day accumulations are also affected.

TABLE 3.3.6

Low Boreal Wetland Region climate statistics*

CLIMATE ELEMENT		Mean	Range
Bright Sunshine (hours)**		1920	1738 to 2203
Precipitation (mm)	— Annual	772	573 to 1000
Snowfall (cm)	— Annual	232	117 to 352
Temperature (°C)	— Annual	1.3	−0.9 to 2.5
	— January	−17.8	−15.4 to −20.1
	— July	17.5	15.6 to 19.2
Growing Degree-days (°C)		1418	1132 to 1733
Growing Season (days)		144	128 to 165
Freeze-free days (days)		157	145 to 177

* Statistics compiled for the period 1951 to 1980 from 16 stations within the Low Boreal Wetland region of the Northern Wetlands Study area.

** Based on 6 stations.

Vegetation, Soils and Wildlife

The Low Boreal Wetland Region includes portions of the Superior, Lower English River and Upper English River Forest Sections of the Boreal Forest Region as well as all of the Quetico Forest Section of the Great Lakes-St. Lawrence Forest Region (Rowe 1972, Section 2.8). This area has the most diverse assemblage of tree species within the Northern Wetlands Study area. Young forests are characterized by deciduous species such as trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*). Coniferous forests of white spruce (*Picea glauca*), black spruce (P. *mariana*), balsam fir (*Abies balsamea*) and white pine (*Pinus strobus*) represent later successional stages in this region (Ecoregions Working Group 1989). The driest sites support jack pine (*Pinus banksiana*), red pine (*P. resinosa*) and white birch whereas wetter sites are characterized by black spruce, white spruce, balsam fir, tamarack (*Larix laricina*), eastern white cedar (*Thuja occidentalis*) and willow (*Salix* spp.). Black ash (*Fraxinus nigra*), red ash (*F. pennsylvanica*), bur oak (*Quercus macrocarpa*) and white elm (*Ulnus americana*) occur in the more westerly portions of this region.

Soils are dominantly Humo-Ferric Podzols and Dystric Brunisols in the vicinity of Thunder Bay and in the Québec portion. Eutric and Dystric Brunisols and Gray

Luvisols occur in the west where sediments tend to be finer textured reflecting the influence of glacial Lake Agassiz. Gleysolic and Organic soils are widespread in low areas where the clays are most poorly drained.

Wildlife which is common to this wetland region include moose, black bear, timber wolf, lynx, white-tailed deer (in the east), woodchuck (in the west), snowshoe hare, hooded merganser, black duck, wood duck and pileated woodpecker (Ecoregions Working Group 1989).

3.3.3.2 WETLAND CHARACTERISTICS

Wetland occurrence and characteristics within the Low Boreal Wetland Region of the Northern Wetlands Study area are subdivided into two major areas (Table 3.3.7). The flat to weakly broken glaciolacustrine plains surrounding the Lake of the Woods form the most extensive wetland areas within this wetland region. Wetlands occupy at least 26 percent of the area with occurrences of greater than 75 percent to the west of the lake and between 50 and 75 percent southeast of the lake.

The Experimental Lakes Area (Kenora) research site lies within the area mapped as having between 26 and 50 percent of the terrain occupied by wetlands (National Wetlands Working Group 1986). The actual occurrence of wetlands in the Experimental Lakes Site is less than 10 percent of the total area (Rubec 1976). The Experimental Lakes Area lies within the portion of the Low Boreal which is primarily bedrock-controlled with isolated wetlands occupying between 6 and 25 percent of the landscape.

Peat thickness averages about 500 cm throughout the Low Boreal, with individual basin bogs having 1,000 cm or more of peat (Wickware and Rubec 1988).

Wetlands within the Experimental Lakes Area were investigated by Rubec (1976) and Wickware (1977). This area is primarily bedrock-controlled with coarse morainal material on uplands. Glaciolacustrine deposits are confined to depressions. Wetlands in this area primarily consist of basin bogs (treed bog) with a minor basin fen component (graminoid fen).

Graham and Tibbets (1965) and Graham (1979) provide detailed descriptions of selected peat deposits in northwestern Ontario, including the Low Boreal Wetland Region. These studies were undertaken to assess the properties of the peat and identify quantities of peat for commercial use including fuel peat and horticultural peat. Wetlands of the Experimental Lakes Area were investigated in order to determine wetland processes and characteristics with regard to the retention and release of sulphur (Bayley *et al.* 1986). These studies were undertaken to determine the ecological effects of acid deposition on peatlands.

3.3.3.3 WETLAND TYPES

Wetlands of the Low Boreal Wetland Region are predominantly domed bogs, basin bogs, basin fens, conifer swamps (dominated by white cedar or black spruce) and hardwood swamps (Zoltai *et al.* 1988b). Table 3.3.8 provides data on peat depth and groundwater chemistry for four wetland physiognomic types representing 27 sites in the Experimental Lakes Area.

Hardwood Swamps

Hardwood swamps are minerotrophic wetlands. They reach their most northerly extent in the Low Boreal Wetland Region where they are located on riverine floodplains and on shallow poorly drained depressions floored with glaciolacustrine silts and clays. Hardwood swamps have up to 2 m of peat (Zoltai *et al.* 1988b), however, peat accumulation is not favoured due to rapid decomposition as a result of relatively warm temperatures and relatively good drainage.

The dominant tree species of hardwood swamps is black ash (*Fraxinus nigra*) which may reach heights of 30 m (Zoltai *et al.* 1988b). Other trees may include American elm (*Ulmus americana*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*) and white birch (*Betula papyrifera*). Understorey vegetation including shrubs, herbs, ferns and mosses is diverse and luxuriant.

Zoltai *et al.* (1988b) describe a black ash swamp located in southwestern Manitoba. Peat at this site was 114 cm thick consisting of 7 cm of fibrous root mat underlain by well decomposed forest peat. Nutrient levels were very high, contributing to a luxuriant plant growth. The water table was located 4 cm beneath the surface.

Basin Bogs

Rubec (1976) describes the soils and water chemistry of several basin bogs located within the Experimental Lakes Area near Kenora, Ontario. These wetlands were mostly treed bog with a minor component of open bog. Soils were primarily Typic Mesisol or Terric Humisol.

The depth to the water table averaged 35 cm and ranged from 20 cm to 60 cm (11 sites). Peat depths ranged from 1 to 6 m averaging 268 cm (Table 3.3.8).

TABLE 3.3.7

Wetland characteristics of the Low Boreal Wetland Region.

	CANADIAN SHIELD	
	Glaciolacustrine (A)	Ground Moraine/Bedrock (B)
WETLAND TYPES	Basin Bog, Basin Fen, Domed Bog	Basin Bog, Basin Fen, Hardwood Swamp, Conifer Swamp
WETLAND DISTRIBUTION (%)	26 to 100	6 to 25
MORPHOLOGY/SLOPE	flat/level to gently sloping, confined	flat/confined
DEPTH OF PEAT (cm)	500 (average)	500 (average)
DECOMPOSITION	mesic	mesic and humic
WETLAND SOILS	Peaty Phase Rego Gleysol Typic Mesisol	Typic Mesisol Mesic Humisol
SOIL CLIMATE (TEMP./MOISTURE)	Moderately Cold Cryoboreal/ Humid to Subaquic	Cool to Moderately Cool Boreal/ Humid to Subhumid
MEAN ANNUAL GROUND TEMPERATURE (°C)	-	5.2 to 7.4
SURFACE WATER COVER (%)	5.2 to 10	-

SOURCES:
National Wetlands Working Group 1986; Rubec 1976; Wickware and Rubec 1988; Young and Judge 1985; Zoltai *et al.* 1988b.

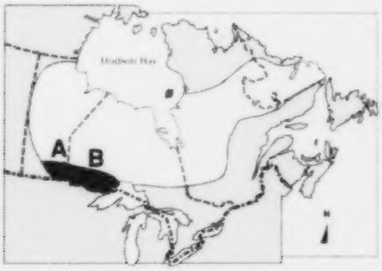


TABLE 3.3.8

Means (standard deviations) for bog (basin bogs), fen (basin fens), marshes and conifer swamps in the Experimental Lakes Area near Kenora, Ontario.

PARAMETER	Basin Bog	Basin Fen	Marsh	Conifer Swamp
No. of Stands	18	3	4	2
Conductivity (μmhos)	40.1(15.3)	45.0(19.07)	60.98(61.02)	29.0(0.57)
pH	3.9(0.29)	4.9(0.89)	5.68(1.09)	4.9(0.35)
Peat Depth (cm)	268.30(180.96)	71.67(67.88)	112.00(9.34)	63.5(61.52)
Major Ions:				
Ca^{++} (mg/L)	1.33(0.64)	4.21(3.12)	7.58(8.28)	3.74(0.75)
Mg^{++} (mg/L)	0.55(0.14)	1.58(1.17)	2.70(3.00)	0.95(0.11)
Na^{+} (mg/L)	1.21(0.52)	2.25(1.33)	1.79(0.99)	2.25(1.36)
K^{+} (mg/L)	1.67(1.56)	1.05(0.51)	0.61(0.50)	0.95(1.22)
Fe^{++} (mg/L)	0.61(0.35)	1.73(2.07)	0.23(0.21)	0.73(0.11)
Cl^{-} (mg/L)	1.18(0.31)	1.13(1.03)	1.20(0.43)	2.50(2.12)
$SO4^{-}$ (mg/L)	7.68(2.29)	10.47(6.79)	5.45(3.28)	8.50(0.71)
Si (mg/L)	4.58(2.98)	5.38(4.49)	5.67(3.67)	9.21(5.23)

SOURCE: Wickware 1977, Rubec 1976

The peat was composed predominantly of moderately to well decomposed sphagnum moss with a thin fibric upper strata. Soil temperatures recorded in the wetland sites showed a variation in the temperature regime from the surface downward. Temperatures within the upper 35 cm ranged between 12°C and 18°C with subsurface temperatures between 8°C (at 220 cm) and 15°C (at 80 cm), respectively. The surface temperature of a basin fen (floating graminoid fen at the margin of a lake) was measured as 22°C decreasing to 13°C at 160 cm. The surface temperature was influenced by heating of the shallow lake water.

Treed bog formed the major physiognomic type followed by low shrub and graminoid bog. The dominant species in treed bogs include black spruce (*Picea mariana*), leather-leaf (*Chamaedaphne calyculata*), Labrador tea (*Ledum groenlandicum*), swamp-laurel (*Kalmia polifolia*) and mosses (*Sphagnum angustifolium*, *S.* fallax, *S. magellanicum* and *Pleurozium schreberi*). Low shrub bogs were characterized by leather-leaf, sweet gale (*Myrica gale*), bog-rosemary (*Andromeda glaucophylla*), sedges (*Carex rostrata* and *C. oligosperma*), *Sphagnum magellanicum* and *S. angustifolium* (Wickware 1977).

Basin Fen

Three basin fens with low nutrient and pH levels (poor fen, Table 3.3.8) were described by Wickware (1977) at the Experimental Lakes Area. Characteristic vegetation included sweet gale, leather-leaf, sedges (*Carex* spp.), *Sphagnum fallax* and *Sphagnum girgensohnii*. Peat depth averaged only 72 cm (Table 3.3.8).

3.3.3.4 LOW BOREAL TOPOSEQUENCE

Figure 3.3.3 illustrates landform-soil-wetland type relationships for the bedrock-controlled ground moraine terrain characteristic of the Experimental Lakes Area research site. Wetlands are predominantly basin bog and basin fen developed by the filling-in of depressions and lakes. Nutrient status tends to be low in most wetlands. Fens commonly have relatively low pH and *Sphagnum* spp. are usually present in the ground layer. Basin bogs are dominated by sphagnum peats indicating ombrotrophic conditions existed throughout the development of the wetland. Basin fens form by terrestrialization of lakes and can be observed in all stages including floating fen margins (Figure 3.3.3) and complete terrestrialization. Minerotrophic inputs to these wetlands is likely derived from localized glaciolacustrine clay deposits within the basin or via streamwater enriched by these deposits in upstream locations.

Image 3.3.1 shows a portion of the Low Boreal in the vicinity of Kenora, Ontario. The image displays the poorly-organized drainage typical of Shield terrain. The lakes occupy bedrock-controlled depressions which have been accentuated by glacial erosion. Wetlands throughout most of this area occupy small depressions and are not visible at this scale. Widespread peatlands typical of the glaciolacustrine deposits of the Low Boreal are visible in the lower left of the image.

FIGURE 3.3.3

Toposequence for the Low Boreal Wetland Region illustrating the relationships among soils, wetland types and landform in the bedrock-controlled terrain of the Experimental Lakes area research site.

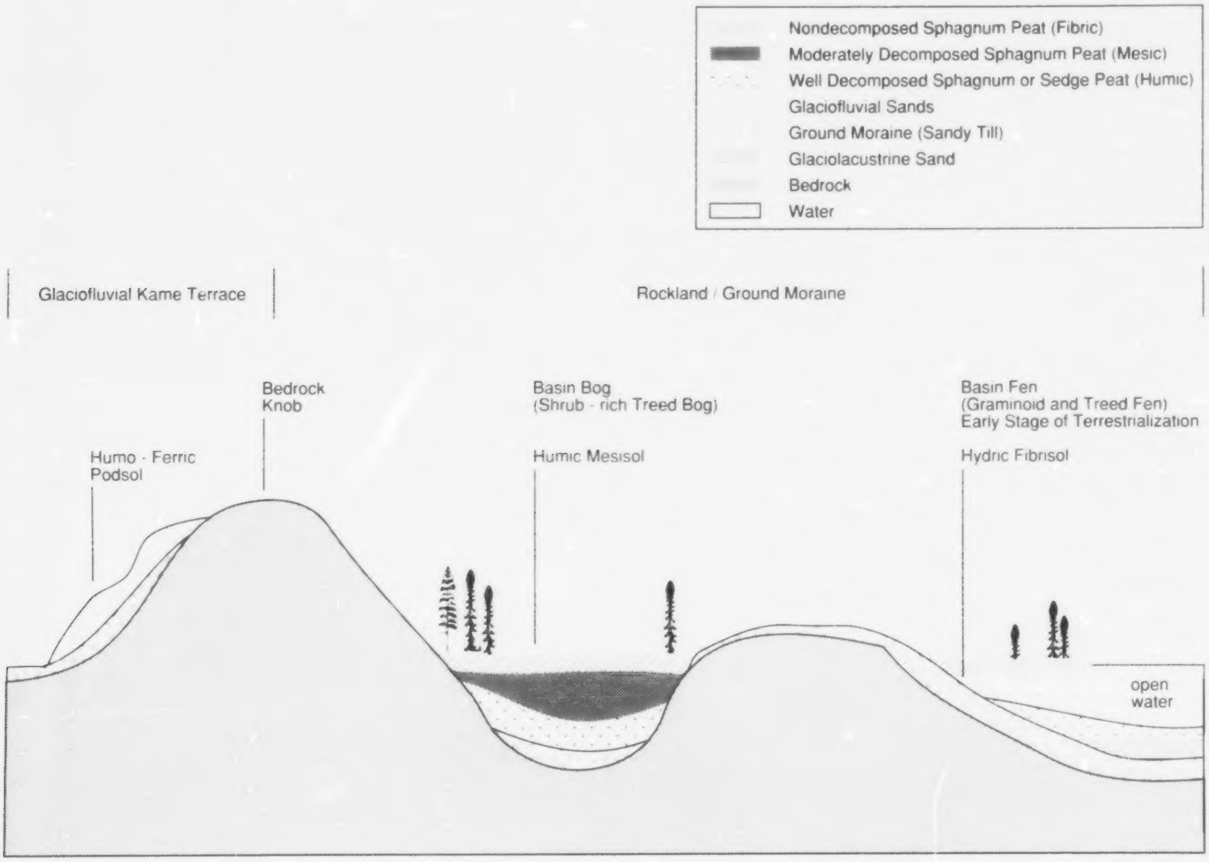
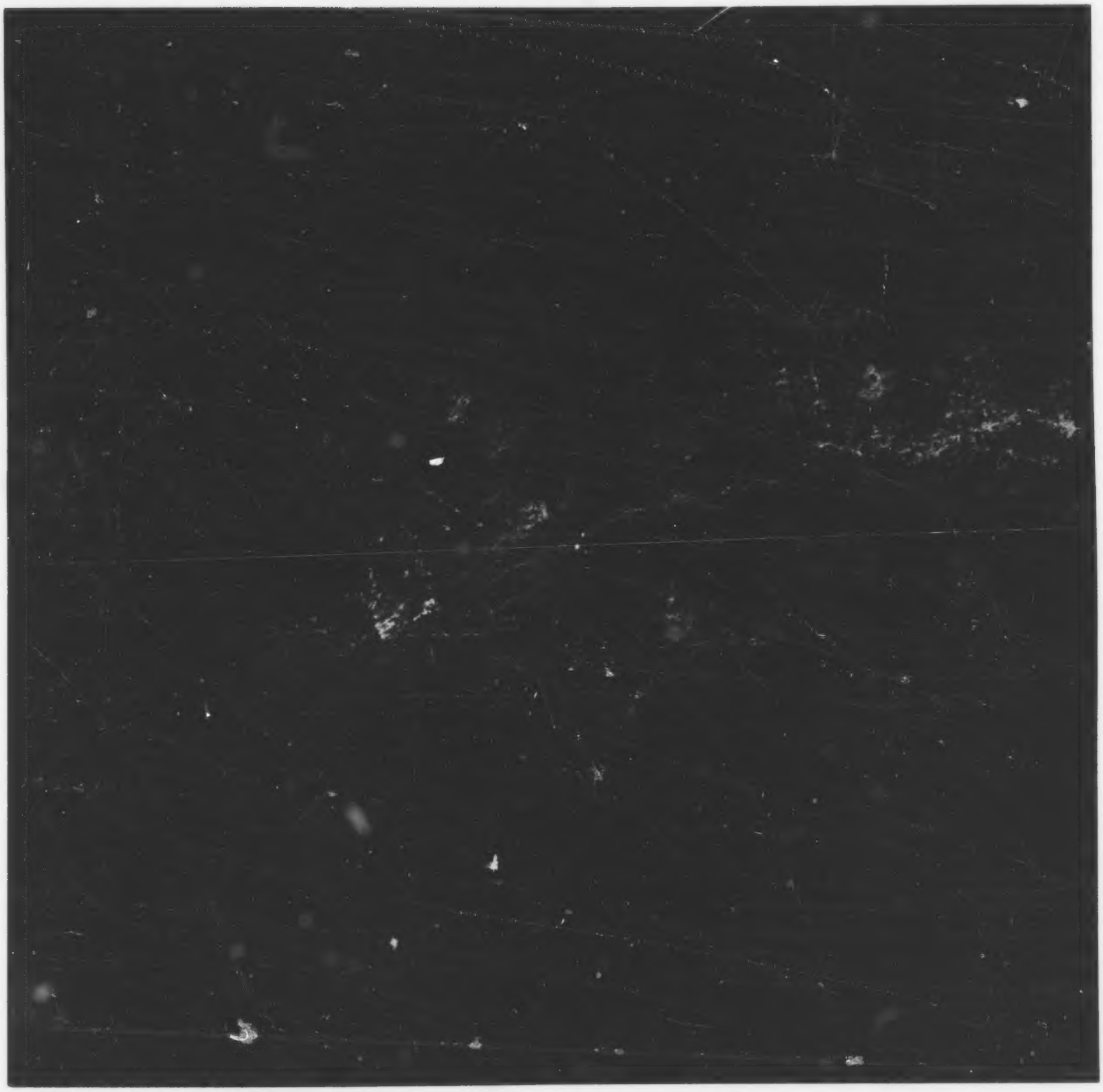

Nondecomposed Sphagnum Peat (Fibric)
Moderately Decomposed Sphagnum Peat (Mesic)
Well Decomposed Sphagnum or Sedge Peat (Humic)
Glaciofluvial Sands
Ground Moraine (Sandy Till)
Glaciolacustrine Sand
Bedrock
Water
Glaciofluvial Kame Terrace
Rockland / Ground Moraine
Bedrock Knob
Humo - Ferric Podsol
Basin Bog (Shrub - rich Treed Bog)
Humic Mesisol
Basin Fen (Graminoid and Treed Fen) Early Stage of Terrestrialization
Hydric Fibrisol
open water

IMAGE 3.3.1

Landsat multispectral image (bands 4, 5 and 7) of the Low Boreal Wetland Region in the vicinity of Kenora, Ontario. The large lake in the south-central portion of the image is Lake of the Woods with the townsite of Kenora located on its northern shore (light tone, just left of centre). Glaciolacustrine plains of glacial Lake Agassiz occur in the southwest corner (Manitoba and Minnesota) and in the east centre. Dryden, Ontario is located on the plain immediately east of the image. The image was recorded on November 24, 1975 and is at a scale of 1:1 million.



3.3.4 ATLANTIC BOREAL WETLAND REGION

3.3.4.1 ENVIRONMENTAL SETTING

Physiography

The Atlantic Boreal Wetland Region occupies virtually all of Labrador within the Northern Wetlands Study area as well as a large portion of east-central Québec (Map 3.1.1). It includes the Schefferville research site which is located at the northern edge of the Atlantic Boreal, transitional to the Low Sub-arctic Wetland Region.

The Atlantic Boreal occupies portions of 3 Physiographic Regions (James, Davis and Laurentian) encompassing all or portions of 9 Physiographic Divisions (Section 2.5.2). The physiography of the Atlantic Boreal Wetland Region is very complex consisting of uplands, plateaux, hills, plains and lowlands.

Although complex, between 80 and 90 percent of the physiography of the Atlantic Boreal Wetland Region is characterized by bedrock-controlled plateaux. The Lake and Kaniapiskau Plateaux of the James Physiographic Region form the greater part of the wetland region in Québec. In Labrador, the wetland region is composed of the Lake Plateau, the George Plateau (Davis Region), and the Hamilton and Mecatina Plateaux of the Laurentian Physiographic Region. Surface elevations of the plateaux within the region average 300 m for the Mecatina Plateau in eastern Labrador; 600 m for the George Plateau in north-central Labrador; and 760 to 910 m on the Kaniapiskau and Lake Plateaux in western Labrador and Québec (Bostock 1970).

The topography of the plateaux ranges from gently undulating and rolling (Lake and George Plateaux) to rugged hills cut by deep fault structures (Kaniapiskau Plateau). The Hamilton Upland and Hamilton Plateau trend northeast-southwest through central Labrador. These two divisions are described by Bostock (1970) as an area of broken terrain. The upland consists of rugged hills up to 760 m in elevation rising 150 to 300 m above the surrounding plateau surface which is covered with moderate to thick morainal material. To the east, the Hamilton Plateau consists of a gently undulating glacial drift-covered surface.

The high plateaux areas within the central and western portions of the Atlantic Boreal Wetland Region served as a centre of ice accumulation and deglaciation for the Laurentide Glacier during the Wisconsin Glaciation (Bryson *et al.* 1969, Bird 1972). The plateaux surfaces were severely eroded during the period of ice accumulation and glacial advance. The material produced by this erosion was carried toward the front of the glacier and deposited in southern Ontario and Québec. The ice stagnated in the late Wisconsin and retreated toward the plateaux of the Atlantic Boreal Wetland Region which became a centre of deglaciation. During this late stage in the Laurentide Glacier, the material produced by erosion was deposited locally on and immediately surrounding the plateaux. Thus, although most of the Shield area of Québec has only thin to non-existent glacial drift, low areas between the hills and rock plains of southern Labrador and east-central Québec have extensive deposits of glacial material.

This material varies in thickness and ranges from compact drumlinized basal till to sandy ablation till and outwash deposits. Gilbert *et al.* (1985) identified glacial moraine deposits 70 m or more in thickness on the Lake Plateau. Lopoukhine *et al.* (1978) also described extensive drumlinized till plains with glaciofluvial (kames and eskers) landforms in many of the valleys. These till plains are often associated with extensive wetland development in the Atlantic Boreal Wetland Region. Drumlinized till plains are particularly favourable for wetland development because they consist of compact till which restricts vertical drainage and drumlin landforms which impede surface runoff.

Climate

The Atlantic Boreal has the harshest climate of the boreal wetland regions (Table 3.3.9). In comparison with the High Boreal Wetland Region, it has lower mean annual temperatures, cooler summer temperatures, a shorter growing season and fewer hours of bright sunshine. The causes, in part, are: the longer domination by Arctic airstreams in the east than in the west; and

TABLE 3.3.9

Atlantic Boreal Wetland Region climate statistics*

CLIMATE ELEMENT		Mean	Range
Bright Sunshine (hrs)**		1534	1497 to 1572
Precipitation (mm)	— Annual	752	595 to 963
Snowfall (cm)	— Annual	348	244 to 481
Temperature(°C)	— Annual	-3.8	0.0 to -5.4
	— January	-21.4	-16.4 to -23.9
	— July	13.4	11.5 to 15.8
Growing Degree-days (°C)		685	485 to 1022
Growing Season (days)		107	94 to 135
Freeze-free days		119	99 to 123

* Statistics compiled for the period 1951 to 1980 from 8 stations within the Atlantic Boreal region of the Northern Wetlands Study area.

** Based on 4 stations.

the southward rise in elevation from Ungava Bay to just north of the St. Lawrence River which counteracts any warming effect of more southerly latitudes.

Total annual precipitation is greater than the High or Mid Boreal Wetland Regions. Snowfall is very heavy. Melting of the deep snow cover delays warming in the spring and contributes to the lower mean annual temperature for the region. In the summertime, rainfall is often heavy and thunderstorms occur frequently. At this time, warm humid air and associated frontal activity is more common.

Goose Bay, located in close proximity to water, has warmer temperatures, a longer growing season, more growing degree-days and more precipitation than Schefferville. Schefferville is located in the northern part of the region in the transition to the High Sub-arctic Wetland Region.

Vegetation, Soils, Permafrost and Wildlife

The Atlantic Boreal Wetland Region corresponds to the Northeastern Transition and Newfoundland-Labrador Barrens Forest Sections of the Boreal Forest Region as defined by Rowe (1972, Section 2.8). Hare (1959) classified the central and western areas as Open Boreal Woodland and the eastern portion as Poor Spruce-Fir Forest. The vegetation of upland sites throughout most of this wetland region is essentially the same as those described in Section 3.2.2.1 for the Low Sub-arctic Wetland Region. The northernmost portion of this region along the border between Québec and Labrador is the same as described for the High Sub-arctic Wetland Region (Section 3.2.1.1). In the vicinity of Lake Melville and Goose Bay, Labrador, balsam fir (*Abies balsamea*) and white birch (*Betula papyrifera*) appear as minor species within the black spruce (*Picea mariana*) dominated lichen-woodlands.

In southern and central Labrador and eastern Québec, soils are predominantly Humo-Ferric and Ferro-Humic Podzols developed on ground moraine, outwash and coarse marine deposits. Hard layers formed from the cementation of soil materials by organic material ('Ortstein' layers) are common in these soils (Lopoukhine *et al.* 1978). Such layers often render the soil impermeable even though it is composed of coarse textured materials. Over wide areas, restricted drainage on these podzols can result in initiation and/or expansion of wetland conditions. Soils occurring in more northerly locations and at higher elevations include Brunisolic Cryosols and Dystric and Eutric Brunisols (Lopoukhine *et al.* 1978). Organic soils are primarily Terric Fibrisols and Terric Mesisols in lowland areas and poorly drained moraine and marine deposits. Gleysols are common at the margin of organic deposits, in shallow depressions and along seepage slopes (Lopoukhine *et al.* 1978).

The Atlantic Boreal Wetland Region is almost entirely within the zone of scattered permafrost. The northernmost portion of this wetland region, in the vicinity of Schefferville, is within the widespread permafrost zone. This corresponds approximately with the boundary between the Atlantic Boreal and the High Sub-arctic Wetland Regions. The permafrost in the vicinity of Schefferville is discontinuous but where it occurs it is up to 125 m in thickness with ground temperatures ranging from −1.1°C to −0.3°C between 7.5 m and 58 m depth (Brown 1967, 1978). Nicholson and Granberg (1973) report a thickness in excess of 100 m for the Timmins 4 Permafrost Experimental Site located on bedrock terrain approximately 20 km northwest of Schefferville (also, Granberg *et al.* 1983).

Results of ground temperature studies reported by Nicholson and Granberg (1973) at this site indicate a positive correlation between ground temperature and depth of snow cover. This may explain why permafrost is generally not found in wetland sites in this area (Allington 1961) as they tend to collect more snow cover than bedrock upland sites. At the Ferriman Permafrost Experimental Site (approximately 8 km southwest of Schefferville) surface ground temperature was found to change rapidly from early December to early January and cold was found to penetrate deeply due to lack of snow accumulation (Etkin *et al.* 1988).

Wildlife species within the Atlantic Boreal Wetland Region includes caribou and moose (winter range), black bear, red fox, arctic fox, snowshoe hare, spruce grouse and Canada goose (EWG 1989).

3.3.4.2 WETLAND CHARACTERISTICS

Regional information on wetland types, their distribution, soils and surface water cover are presented in Table 3.3.10 for two main subdivisions of the Atlantic Boreal. Within the Northern Wetland Study area, this wetland region is primarily represented by the Interior Atlantic Boreal (National Wetlands Working Group 1986), which corresponds to the interior plateau area (area A, Table 3.3.10), and by the Eastern Atlantic Boreal which is identified as the eastern plateau (area B). A small portion of the Northern Atlantic Boreal, as defined by the National Wetlands Working Group (1986), occurs along the southwestern Québec-Labrador boundary.

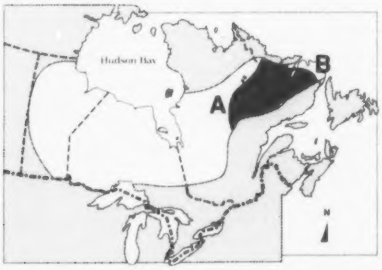
Within both areas, isolated wetlands are found in bedrock-controlled depressions such as basins and

TABLE 3.3.10

Wetland characteristics of the Atlantic Boreal Wetland Region.

	CANADIAN SHIELD	
	Interior Plateau (A)	Eastern Plateau (B)
WETLAND TYPES	String Bog, Basin Bog, Palsa Bog, Atlantic Ribbed Fen, Slope Fen, Basin Fen, Horizontal Fen	String Bog, Domed Bog, Atlantic Ribbed Fen
WETLAND DISTRIBUTION (%)	6 to 25 26 to 50 (locally)	6 to 25 26 to 50 (locally)
MORPHOLOGY/SLOPE	flat, hummocky/gently sloping to level, confined	domed, flat/gently sloping to level
DEPTH OF PEAT (cm)	100 (average for ribbed fens)	150 (average string bogs)
DECOMPOSITION	fibric and mesic	fibric and mesic
WETLAND SOILS	Terric Fibrisol Terric Fibric Mesisol	Terric Fibric Mesisol
SOIL CLIMATE (TEMP./MOISTURE)	Cold Cryoboreal to Very Cold Subarctic/Perhumid	Cold Cryoboreal/Perhumid
MEAN ANNUAL GROUND TEMPERATURE (°C)	0.8 (Schefferville) to 0.9	4.6
SURFACE WATER COVER (%)	15 to 25	5 to 15

SOURCES:
Allington 1961; Clayton *et al.* 1977; Gerardin *et al.* 1984; Gerardin and Grondin 1987; Gilbert *et al.* 1985; Lopoukhine *et al.* 1978; National Wetlands Working Group 1986; Wells and Hirvonen 1988; Young and Judge 1985



along faults. Wetlands reach their greatest development on areas of compact tills, especially drumlinized till plains where they may cover 50 percent of the terrain. Climatically, the Atlantic Boreal is comparable to the Low Sub-arctic at higher elevations and the High Boreal in more protected locations. Peat thickness averages only 100 to 150 cm which is in the same range as the Low Sub-arctic. Treed peatlands particularly treed bog and conifer swamp types are not as common in the Atlantic Boreal as in Sub-arctic and other Boreal Wetland Regions.

Hare (1959) defines a 'Wet Series' for the Labrador-Ungava peninsula which consists of muskeg (treed bog), bog (string bog), fen (horizontal and ribbed fen), palsas and alder and willow thickets (thicket swamp). He estimates about 10 percent of the total peninsula consists of this wet series.

Allington (1961) describes bogs and fens (she uses the term bog to include both) of the Knob Lake area in the vicinity of Schefferville. The area has a topography of valleys and ridges and lies within the Labrador Hills Physiographic District. The bedrock geology includes metamorphosed sedimentary rocks which provide a source of base-rich material unlike most of central Labrador and Québec which consists of granite and granite gneiss (Section 2.5.3). Allington (1961) cites Hustich (1949, 1954) as relating the luxuriant vegetation growth in the valleys of this area to be a result of the sedimentary rocks and associated glacial deposits (till and localized glaciolacustrine clays). Hustich (1949, 1954) notes that treed bog peatlands are characteristic of the granite terrain whereas they are less common on the sedimentary terrain which is characterized by swamps rich in tamarack.

Allington (1961) classifies the bogs and fens on the basis of appearance as defined by the major vegetation types and patterns. Her types include string bog and closed string bog differentiated by the presence or absence of open water (likely a combination of string bog and ribbed fen types); sedge meadow (likely basin fen); bog forest (treed bog, likely basin bog and plateau bog); and tamarack swamp forest (treed fen, likely horizontal fen). Tamarack swamp forest is restricted to the Knob Lake area within the Atlantic Boreal. Peat depths in this area average about 2 m with individual basins containing peat deposits up to 4 m or more. Permafrost was not found in this area, however, Allington (1961) notes that palsa bogs have been reported to the northwest.

Gerardin *et al.* (1984) and Gerardin and Grondin (1987) provide detailed descriptions of the flora, peat thickness and distribution of bogs and fens of the Moyenne-et-Basse-Côté-Nord region of Québec. The wetland region identified by Gerardin *et al.* (1984) as 'Le plateau du Labrador' includes the southernmost portion of the Atlantic Boreal Wetland Region occurring in the Northern Wetlands Study area. Peatlands cover between 2 to 20 percent (overall average of 5 percent) of the surface area of the plateau du Labrador. Fens are more widespread than bogs with Atlantic ribbed fens (referred to as open 'structured' fens by the authors) forming 35 percent of the peatlands; graminoid and treed horizontal fens ('uniform' fen) making-up 25 percent; domed bog ('ribbed' and 'uniform' bog) about 35 percent; and string bog ('structured' bog) less than 5 percent of the total peatland area. Many of the bogs and fens of this area are similar to those described for the Mid Boreal Wetland Region. Peat thickness ranges from 90 cm to greater than 100 cm. The wetlands are grouped on the basis of dominant species and trophic status ('ecological group') for which specific data on pH, carbon/nitrogen ratios, geomorphic type, seepage, physiognomy, altitudinal range and distribution according to latitude and longitude are provided (Gerardin *et al.* 1984).

3.3.4.3 WETLAND TYPES

The dominant wetlands of the Atlantic Boreal Wetland Region within the Northern Wetlands Study area are Atlantic ribbed fens and string bogs in lowland areas and basin bogs and slope fens in upland areas (Wells and Hirvonen 1988). Carbonate till and clay deposits in the Schefferville area also permit the development of basin fens and horizontal fens (Allington 1961).

String Bogs

String bogs are very gradually sloping ombrotrophic wetlands with a distinctive pattern of strings alternating with linear bog pools oriented at right angles to the direction of slope (Pollett and Wells 1981). These peatlands are best expressed within the Atlantic Boreal in Labrador, especially in the eastern plateau area (Wells and Hirvonen 1988). String bogs are treeless with surface vegetation consisting primarily of sphagnum mosses and shrubs on the strings. The underlying peat is loose and stringy, composed primarily of sphagnum and sedge remains (Pollett and Wells 1981). Peat depths in these bogs is generally between 1 and 2 m.

Characteristic species of wet bog communities in Labrador include sheep-laurel (*Kalmia angustifolia*), bog-bilberry (*Vaccinium uliginosum*), crowberry (*Empetrum nigrum*), cloudberry (*Rubus chamaemorus*), cotton grass (*Eriophorum spissum*), *Carex rariflora*, *Ochrolechia frigida, Ptilidium ciliare, Cornicularia aculeata* and sphagnum mosses (*Sphagnum compactum, S. lindbergii, S. rubellum* and *S. angustifolium*) (Wells and Hirvonen 1988).

Atlantic Ribbed Fens

Atlantic ribbed fens are similar in morphology and landscape position as string bogs but receive minerotrophic inputs. They are best developed in western Labrador but also occur on the eastern plateau and in the Atlantic Sub-arctic Wetland Region. Atlantic ribbed fens are characterized by an abundance of pools and have a surface slope of between 5 and 30 percent (Pollett and Wells 1981). The pools vary in shape from long and linear on steep slopes to irregular and discontinuous on flatter slopes. Peat thickness averages 1 to 2 m.

Characteristic species on the strings are *Vaccinium uliginosum, Carex limosa, Cladopodiella fluitans, Ptilidium ciliare, Sphagnum angustifolium* and *S. compactum*. Wetter communities include *Vaccinium uliginosum, Rubus acaulis, Betula glandulosa, Cladopodiella fluitans, Carex limosa, Calliergon stramineum, Coptis groenlandica, Sphagnum warnstorfii, S. pulchrum, S. magellanicum*, and *S. rubellum* (Wells and Hirvonen 1988).

Slope Fens

Slope fens are restricted to upland areas within the Atlantic Boreal Wetland Region. They are minerotrophic wetlands which are physiographically and floristically similar to Atlantic ribbed fens but generally lack pools. Small pools may be present but they seldom form patterns (Pollett and Wells 1981). The surface of the fens slope at between 5 and 30 percent and are often bordered at the base by a drainage channel. The surface of the fen may also be cut by a drainage channel. They have peat depths of 1 to 2 m (Wells and Hirvonen 1988).

3.3.4.4 ATLANTIC BOREAL TOPOSEQUENCE

Figure 3.3.4 provides cross-sectional diagrams showing soil-landform-vegetation relationships for three typical Atlantic Boreal wetland types: string bog (A), Atlantic ribbed fen (B) and slope fen (C). All three types of peatland are localized in extent. Trees are occur sporadically if at all.

String bogs and Atlantic ribbed fens occur over large areas of eastern and western Labrador. They occur on poorly drained slopes of upland bedrock and moraine terrains. String bogs occur in areas of low-base soils and in isolation from minerotrophic waters. Ribbed fens and slope fens occur in association with carbonate-rich soils and/or a supply of minerotrophic water from upstream areas. Slope fens and string bogs are usually continuous whereas Atlantic ribbed fens may be discontinuous with bedrock outcrops or glacial erratics protruding through the peat.

The Atlantic Boreal Wetland Region in the vicinity of Schefferville, Québec is shown in Image 3.3.2. Wetlands are not clearly visible due to their small size. They are most abundant in the valleys associated with the northwest-southeast trending geologic structures near Schefferville. This image illustrates variations in terrain resulting from differences in bedrock structure and type. The relatively hard granitic bedrock of the Kaniapiskau Plateau produces a less scoured, smoother surface (southwest) than the deeply scoured metamorphosed volcanic and sedimentary bedrock of the Labrador Hills and Whale Lowland (Maps 2.5.2 and 2.5.3). The volcanic and sedimentary bedrock has a greater proportion of base-rich minerals permitting the formation of minerotrophic wetlands.

3.4 REFERENCES

Allington, K.R. 1961. The bogs of central Labrador-Ungava; an examination of their physical characteristics. *Geografiska annaler*, 43(3-4): 401-417.

Bates, D.N. and D. Simkin. 1969. Vegetation patterns of the Hudson Bay Lowland. Ont. Min. Nat. Res., Research Branch, Map 3269.

Bayley, S.E., R.S. Behr and C.A. Kelly. 1986. Retention and release of sulphur from a freshwater wetland. *Water, Air, Soil Pollution*, 31(1-2): 101-114.

Bird, J.B. 1972. *The Natural Landscapes of Canada*. Wiley Publishers of Canada Ltd, Toronto, Ontario: 191p.

Bostock, H.S. 1970. Physiographic subdivisions of Canada. *In. Geology and Economic Minerals of Canada*. R.J.W. Douglas (editor), Dept. Energy, Mines and Resources, Queen's Printer, Ottawa: 10-30.

Brown-Beckel, D.K. 1957. Studies on seasonal changes in the temperature gradient of the active layer of soil at Fort Churchill, Manitoba. *Arctic*, 10(3): 151-183.

Brown, R.J.E. 1967. Permafrost in Canada. Map 1246A, Geol. Surv. Can., scale 1 in. to 120 mi.

Brown, R.J.E. 1968. Occurrence of permafrost in Canadian peatlands. Proc. 3rd Int. Peat Congress, Québec City, August 1968: 174-181.

Brown, R.J.E. 1978. Permafrost. *In. Hydrological Atlas of Canada*. (text and map) Fisheries and Environment Canada, Supply and Services Canada, Ottawa, Ontario.

Bryson, R.A., W.A. Wendland, J.D. Ives and J.T. Andrews. 1969. Radiocarbon isochrones on the disintegration of the Laurentide Ice Sheet. *Arctic Alpine Res.*, 1: 1-14.

FIGURE 3.3.4

Toposequence for the Atlantic Boreal Wetland Region. Cross-section showing wetland-landscape morphology, peat type, peat humification and major surface vegetation types for String bog (A), Atlantic ribbed fen (B) and slope fen (C) toposequences (from Wells and Hirvonen 1988).

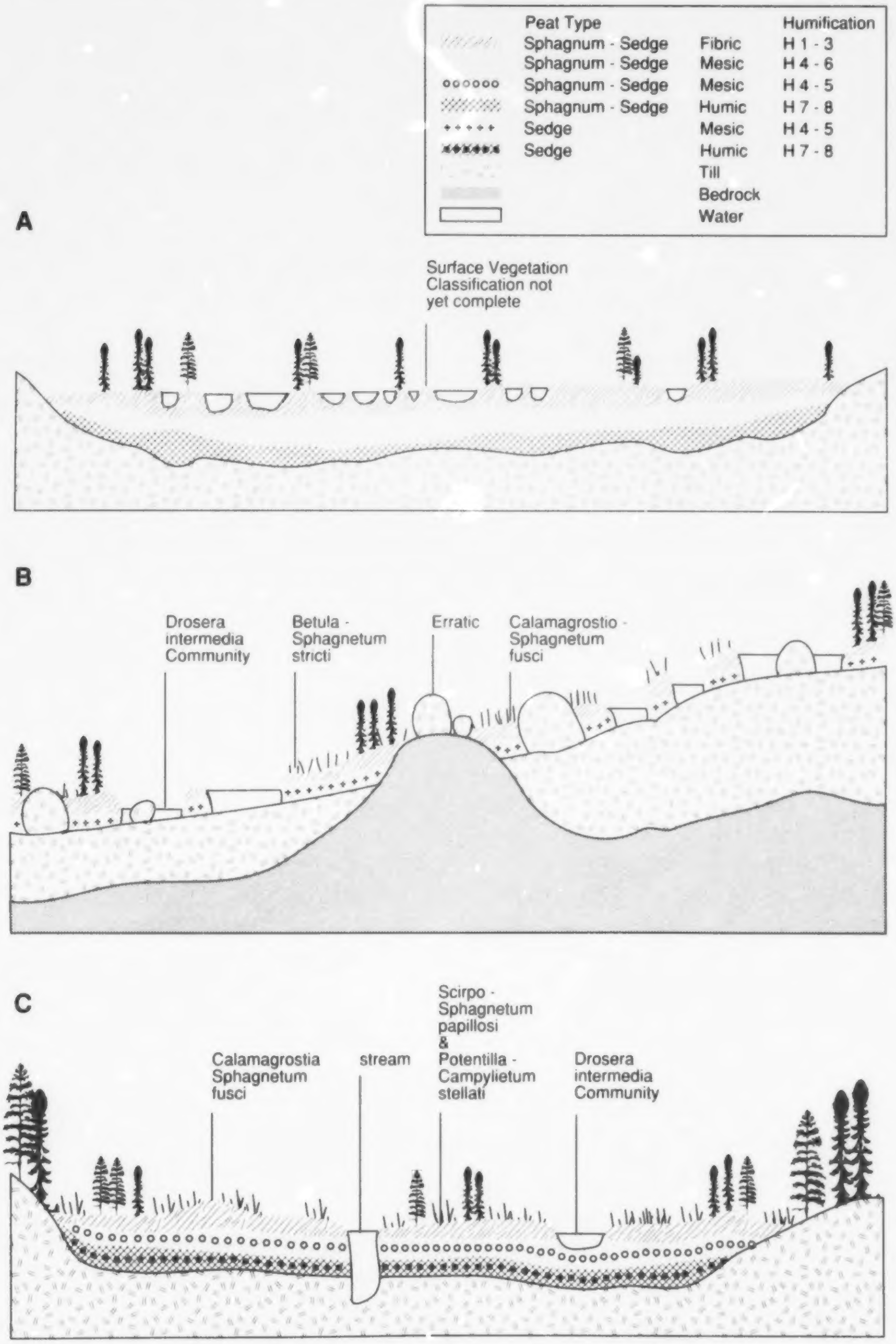
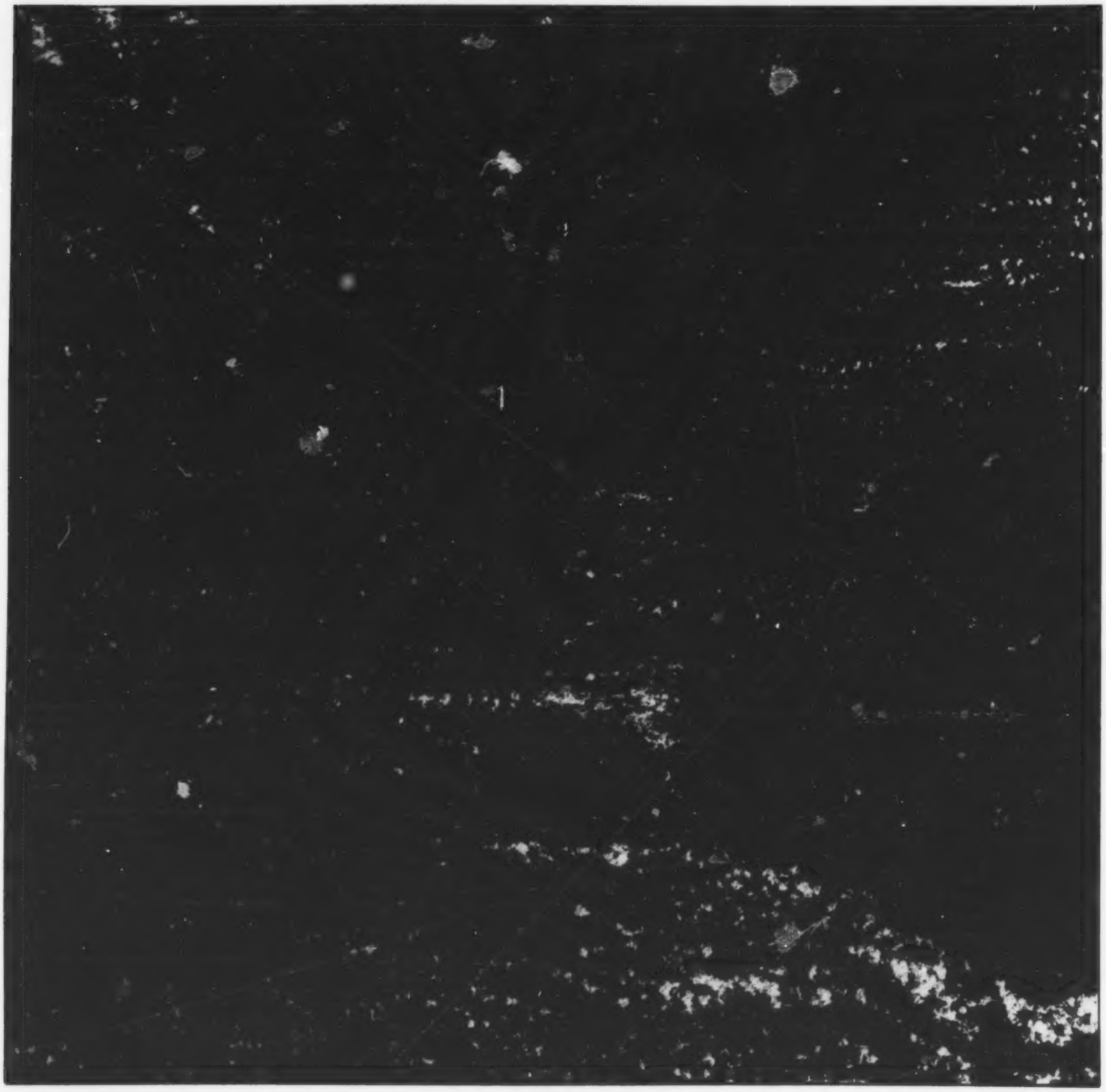

Peat Type
Humification
Sphagnum - Sedge Fibric H 1 - 3
Sphagnum - Sedge Mesic H 4 - 6
Sphagnum - Sedge Mesic H 4 - 5
Sphagnum - Sedge Humic H 7 - 8
Sedge Mesic H 4 - 5
Sedge Humic H 7 - 8
Till
Bedrock
Water
A
Surface Vegetation Classification not yet complete
B
Drosera intermedia Community
Betula - Sphagnetum stricti
Erratic
Calamagrostio - Sphagnetum fusci
C
Calamagrostia Sphagnetum fusci
stream
Scirpo - Sphagnetum papillosi & Potentilla - Campylietum stellati
Drosera intermedia Community

IMAGE 3.3.2

Landsat multispectral image (bands 4, 5 and 7) of the Atlantic Boreal of central Labrador and north-eastern Québec. The townsite of Schefferville, Québec is located in the northwest portion of the image immediately west of the large lake complex. The image was recorded on October 17, 1980 at a scale of 1:1 million.



Bryson, R.A. and F.K. Hare. 1974. The climates of North America. *In. Climates of North America, World Survey of Climatology, Volume 11*, R.A. Bryson and F.K. Hare (editors), Elsevier Scientific Publishing Co., N.Y.: 1-48.

Clarke, K.E., I.P. Martini and W.A. Glooschenko. 1982. Sedimentary characteristics of the coastal environment of North Point, Ontario. *Naturaliste can.*, 109: 385-397.

Clayton, J.S., W.A. Ehrlich, D.B. Cann, J.H. Day and I.B. Marshall. 1977. Soils of Canada. Research Branch, Canada Department of Agriculture, Ottawa, Ontario: 2 volumes plus maps.

Cowell, D.W. 1982. Earth sciences of the Hudson Bay Lowland: literature review and annotated bibliography. Lands Direct. Environment Canada, Ottawa, Ontario, Working Paper No. 18: 309p.

Cowell, D.W., J.K. Jeglum and J.C. Merriman. 1978. Preservation of seasonal frost in peatlands, Kinoje Lakes, southern Hudson Bay Lowland. Proc. 3rd Int. Conf. Permafrost, Edmonton Alta: 453-459.

Cowell, D.W., R.A. Sims and G.M. Wickware. 1982. Frozen beach ridge soils in the Hudson Bay Lowland, Ontario. *Can. J. Soil Science*, 62: 421-425.

Cowell, D.W., G.M. Wickware, J.K. Jeglum, R.A. Sims and A.N. Boissonneau. 1983. Hudson Bay Lowland peatland inventory. Proc. Peatland Inventory Methodology Workshop, Land Res. Research Instit., Agriculture Canada and Newfoundland Forest Research Centre, Environment Canada: 88-102.

Cox, E.T. 1978. Counts and measurements of Ontario lakes. Fisheries Branch, Ontario Ministry of Natural Resources: 114p.

Dai, T.S., V.F. Haavisto and J.H. Sparling. 1973. Water level fluctuation in a northeastern Ontario peatland. *Can. J. Forestry Res.*, 4: 76-81.

Dutchak, K., B. Kerr, G.F. Mills, H. Veldhuis, V. Woo and D.B. Forrester. 1978. Biophysical land classification: Berens River-Deer Lake, 63A-53D, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept. Renewable Resources and Transportation Services: guide and 1:125,000 scale map.

Ecoregions Working Group (EWG). 1989. Ecoclimatic regions of Canada: first approximation. Ecological Land Class. Series No. 23, Canada Com. Ecol. Land Class., Sustainable Development Branch, Canadian Wildlife Service, Environment Canada, Ottawa, Ontario: text and 1:7.5 million scale map.

Etkin, D.A., A. Headley and K.J.L. Stoker. 1988. A long-term permafrost and climate monitoring program in northern Canada. Atmospheric Environment Service, Environment Canada, Downsview, Ontario.

Gerardin, V., P. Grondin and M. Lebel. 1984. Distribution et description des tourbières de la Moyenne-et-Basse-Côté-Nord. Serie de l'Inventaire du Capital-Nature, No. 4, Environnement Québec—Environnement Canada—Hydro Québec, Québec, Québec: 156p.

Gerardin, V. and P. Grondin. 1987. Description and regionalization of peatland forms of Moyenne-et-Basse-Côté-Nord, Québec. Proc. Symp. '87, Edmonton, Alta., ISBN 0-9692186-2-1, Ottawa, Ontario: 393-402.

Gilbert, G., R.G. Helie and J.M. Mondoux. 1985. Ecosystem sensitivity to acid precipitation for Québec. Part A: ecoregions and ecodistricts of Québec. Ecological Land Class. Series No. 20, Lands Direct., Environment Canada, Ottawa, Ontario: 87p. plus 1:2.5 million scale maps.

Glooschenko, W.A., I.P. Martini and K. Clarke-Whistler. 1988. Salt marshes of Canada. Chapter 9. *In. Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 347-377.

Gore, A.J.P. 1983. Introduction. *In. Ecosystems of the world. Volume 4A. Mires: swamp, bog, fen and moor.* A.J.P. Gore, editor. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands: 1-34.

Graham, R.B. 1979. Some peat moss and peat deposits in selected areas; Districts of Nipissing, Sudbury, Algoma, Thunder Bay and Kenora, Ontario. Ontario Geological Survey, MDC No.19: 132p.

Graham, R.B. and T.E. Tibbets. 1965. Evaluation of peat moss in some bogs of the Rainy River District, Ontario. Mines Branch, Canada Dept Mines and Tech. Surveys, Tech. Bull. TB 65, Ottawa, Ontario: 88p.

Granberg, H.B., J.B. Lewis, T.R. Moore, P. Steer and R.K. Wright. 1983. Schefferville permafrost research; Vol. 1. Summary, review and recommendations, and catalogue of available materials. Dept Geog., McGill University: 88p.

Hare, F.K. 1959. A photo-reconnaissance survey of Labrador-Ungava. Geog. Branch, Mines and Technical Surveys, Mem. 6, Ottawa, Ontario: 83p.

Hare, F.K. and J.C. Ritchie. 1972. The boreal bioclimates. *The Geographical Review*, 62(3): 333-365.

Hustich, I. 1949. Phytogeographic regions of Labrador. *Arctic* 2: 36-42.

Hustich, I. 1954. On the forest and tree growth in the Knob Lake area, Québec-Labrador Peninsula. *Acta Geogr.*, 13(1): 1-60.

Jeglum, J.K., A.N. Boissonneau and V.F. Haavisto. 1974. Toward a wetland classification for Ontario. Canadian Forestry Service, Information Report O-X-215, Sault Ste. Marie, Ontario: 54p.

Jeglum, J.K. and D.W. Cowell. 1982. Wetland ecosystems near Kinoje Lakes, southern interior Hudson Bay Lowland. *Naturaliste can.*, 109: 621-635.

Jeglum, J.K., V.F. Haavisto and A. Groot. 1982. Peatland and forestry in Ontario: An overview. *In. Peat Symposium '82*, September, Gov'ts of Canada and New Brunswick and the Can. National Comm. International Peat Society: 25p + appendices.

Jones, R.K., G. Pierpoint, G.M. Wickware, J.K. Jeglum, R.W. Arnup and J.M. Bowles. 1983. Field guide to forest ecosystem classification for the clay belt, Site Region 3e. Agriculture Canada, Environment Canada and Ontario Ministry of Natural Resources, Queen's Printer for Ontario, Maple, Ontario: 123p.

Kalela, A. 1962. Notes on the forest and peatland vegetation in the Canadian Clay Belt Region and adjacent areas. Communicationes Instituti Forestalis Fenniae 55.33, Helsinki, Finland: 19p.

Lafleur, P.M. and W.R. Rouse. 1988. The influence of surface cover and climate on energy partitioning and evaporation in a Sub-arctic wetland. *Boundary-Layer Meteorology*, 44:327-347.

Lopoukhine, N., N.A. Prout and H.E. Hirvonen. 1978. The ecological land classification of Labrador: A reconnaissance. Ecological Land Class. Series No. 4, Lands Dir., Environment Canada, Ottawa, Ontario: 85p. plus 1:1 million scale map.

Manitoba-Canada Soil Survey. 1986. Soil landscapes of Canada: Manitoba. Land Resource Research Institute, Agriculture Canada: 1:1 million scale map sheet.

Martini, I.P. 1981. Morphology and sediments of the emergent Ontario coast of James Bay, Canada. *Geog. Annaler*, 63A: 81-94.

Martini, I.P. and R. Protz. 1978. Coastal geomorphology, sedimentology and pedology of southern James Bay, Ontario, Canada. Department of Land Resource Sciences, University of Guelph, Guelph, Ontario: 118p.

Martini, I.P., R. Protz, D. Grinham, W.A. King and K. Clarke. 1979. Studies of coastal sediments, soils and biota, James Bay, Ontario, Canada. Technical Memo. 79-1, Department of Land Resource Science, University of Guelph, Guelph, Ontario: 290p.

Martini, I.P., R.I.G. Morrison, W.A. Glooschenko and R. Protz. 1980. Coastal studies in James Bay, Ontario. *Geos. Can.* 7 (1): 11-21.

Mills, G.F., H. Veldhuis, D.B. Forrester and R. Schmidt. 1976a. Biophysical land classification: Hayes River 54C, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept. Renewable Resources and Transportation Services: guide and 1:125,000 scale map.

Mills, G.F., H. Veldhuis and D.B. Forrester. 1976b. Biophysical land classification: Kettle Rapids 54D, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept. Renewable Resources and Transportation Services: guide and 1:125,000 scale map.

Mills, G.F., D.B. Forrester and H. Veldhuis. 1978a. Biophysical land classification: Knee Lake 53M, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept. Renewable Resources and Transportation Services: guide and 1:125,000 scale map.

Mills, G.F., H. Veldhuis and D.B. Forrester. 1978b. Biophysical land classification: Oxford House 53L, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept Renewable Resources and Transportation Services: guide and 1:125,000 scale map.

Moore, P.D. and D.J. Bellamy. 1974. *Peatlands*. Springer-Verlag Inc. New York, N.Y.:221p.

National Wetlands Working Group. 1986. Canada's Wetlands: maps of wetland regions and distribution in Canada. Canada Committee on Ecological Land Classification, Lands Directorate, Environment Canada, Ottawa, Ontario: 2 maps at 1:7.5 million scale plus fact sheet.

National Wetlands Working Group. 1988. *Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 452p.

Nicholson, F.H. and H.B. Granberg. 1973. Permafrost and snowcover relationships near Schefferville. Proc. 2nd Int. Conf. Permafrost: 151-158.

Pala, S. and W. Weischet. 1982. Toward a physiographic analysis of the Hudson Bay-James Bay Lowland. *Naturaliste can.*, 109: 637-651.

Pollett, F.C. and E.D. Wells. 1981. Peatlands of Newfoundland-an overview. *In. The diversity of Peat.* F.C. Pollett, A.F. Rayment and A. Robertson (eds), Newfoundland and Labrador Peat Assoc., St. Johns, Newfoundland: 130p.

Protz, R. 1982a. Development of gleysolic soils in the Hudson and James Bay Coastal Zone, Ontario. *Le Naturaliste can.*, 109: 491-500.

Protz, R. 1982b. Development of podzolic soils in the Hudson and James Bay Lowlands, Ontario. *Le Naturaliste can.*, 109: 501-510.

Protz, R., G.J. Ross, I.P. Martini and J. Terasmae. 1984. Rate of podzolic soil formation near Hudson Bay, Ontario. *Can. J. Soil Sci.*, 64: 31-49.

Protz, R., G.J. Ross, M.J. Shipitalo and J. Terasmae. 1988. Podzolic soil development in the southern James Bay Lowlands, Ontario. *Can. J. Soil Sci.*, 68: 287-305.

Railton, J.B. and J.H. Sparling. 1973. Preliminary studies on the ecology of palsa mounds in northern Ontario. *Can. J. Botany*, 51: 1037-1044.

Raveling, D.G. and H.G. Lumsden. 1977. Nesting ecology of Canada geese in the Hudson Bay Lowlands of Ontario: evolution and population regulation. Fish and Wildlife Branch, Ontario Ministry of Natural Resources, Research Report No. 98:77p.

Riley, J.L. 1982. Hudson Bay Lowland floristic inventory, wetlands catalogue and conservation strategy. *Naturaliste can.*, 109: 543-555.

Riley, J.L. 1988. Southern Ontario bogs and fens off the Canadian Shield. *In. Wetlands: Inertia or Momentum Conf. Proceedings*, M.J. Bardecki and N. Patterson (eds), Federation of Ontario Naturalists, Toronto, Ontario: 355-367.

Ritchie, J.C. 1959. The vegetation of northern Manitoba: III. studies in the Sub-arctic. Arctic Institute of North America, Technical Paper 3: 56p.

Ritchie, J.C. 1960. The vegetation of northern Manitoba: VI. the lower Hayes River Region. *Can. J. Botany*, 38: 769-788.

Rouse, W.R. and R.L. Bello. 1985. Impact of Hudson Bay Lowlands and the potential for climatic modification. *Atmosphere-Ocean*, 23(4): 375-392.

Rowe, J.S. 1972. Forest Regions of Canada. Forestry Canada, Pub. No. 1300: 172p.

Rubec, C.D. 1976. Draft report on soils investigations during a biophysical survey of the Experimental Lakes Area, 1976. Draft Unpub. Manuscript, Lands Directorate, Environment Canada, Burlington, Ontario: 81p.

Sims, R.A. and J.M. Stewart. 1981. Aerial biomass distribution in an undisturbed and disturbed Sub-arctic bog. *Can. J. Bot.*, 59(5): 782-786.

Sims, R.A., D.W. Cowell and G.M. Wickware. 1982a. Use of vegetational physiognomy in classifying treed peatlands near southern James Bay, Ontario. *Le Naturaliste. can.*, 109: 611-619.

Sims, R.A., D.W. Cowell and G.M. Wickware. 1982b. Classification of fens near southern James Bay, Ontario using vegetational physiognomy. *Can. J. Botany*, 60(12): 2608-2623.

Sims, R.A., G.M. Wickware and D.W. Cowell. 1987. Wetlands of the southern Hudson Bay coast in Ontario. Proc. Symposium '87 Wetlands/Peatlands, ISBN 0-9692186-2-1, Ottawa, Ontario: 435-442.

Sjörs, H. 1959. Bogs and fens in the Hudson Bay Lowland. *Arctic*, 12(1): 2-19.

Sjörs, H. 1961. Surface patterns in boreal peatland. *Endeavour*, 20: 217-224.

Sjörs, H. 1963. Bogs and fens on Attawapiskat River, northern Ontario. Contributions to Botany 1960-61, National Museum of Canada, Bull. No. 186: 45-133.

Stanek, W. 1973. Classification of Muskeg. Chapter 2. *In. Muskeg and the Northern Environment in Canada*. N.W. Radforth and C.O. Brawner (editors), University of Toronto Press, Toronto: 31-62.

Stanek, W. 1977. Ontario clay belt peatlands-are they suitable for forest drainage? *Can. J. Forestry Research*, 7: 656-665.

Tarnocai, C. 1972. Some characteristics of cryic organic soils in northern Manitoba. *Can. J. Soil Sci.*, 52: 485-496.

Tarnocai, C. 1980. Canadian wetland registry. *In. Proceeding Workshop on Canadian Wetlands.* C.D.A. Rubec and F.C. Pollett (editors). Ecological Land Classification Series No. 12: 9-38.

Tarnocai, C. 1982. Soil and terrain development on the York Factory peninsula, Hudson Bay Lowland. *Naturaliste Can.*, 109: 511-522.

Tarnocai, C. 1984. Peat resources of Canada. Nat. Research Council of Canada #24140: 17p.

Tarnocai, C. 1988. Wetlands in Canada: distribution and characteristics. Abstract *In. Workshop Report, Global Change: Canadian Wetlands Study*, Can. Institute in Atmospheric Chemistry: 82p.

Terasmae, J. 1970. Postglacial muskeg development in northern Ontario. Proc. 13th Muskeg Res. Conf., National Res. Council Associate Committee Geotech. Res., Tech. Memo 99: 73-90.

Thie, J. 1974. Distribution and thawing of permafrost in the southern part of the discontinuous permafrost zone in Manitoba. *Arctic* 27: 189-200.

Veldhuis, H., G.F. Mills and D.B. Forrester. 1979. Biophysical land classification: Slipiwesk 63P and S.E. 1/4 of Split Lake 64A, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept. Renewable Resources and Transportation Services: guide and 1:125,000 scale map.

Wells, E.D. and H.E. Hirvonen. 1988. Wetlands of Atlantic Canada. Chapter 7. *In. Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 249-303.

Wickware, G.M. 1977. Dominant vegetation, water chemistry and peat depth representing 27 wetland sites in the Experimental Lakes Area, Kenora, Ontario. Open File Report #77-1, Geomatics International, Burlington, Ontario.

Wickware and Associates Inc. 1990. Organic and mineral soils of the southern James Bay coastal zone in relation to landform and vegetation physiognomy. Manuscript prepared for R.A. Sims, Great Lakes Forest Centre, Forestry Canada, Sault Ste. Marie, Ontario.

Wickware, G.M. and C.D. Rubec. 1988. Terrestrial ecoregions and ecodistricts of Ontario. Ecological Land Class. Series No. 26, Sustainable Development Branch, Environment Canada, Ottawa, Ontario: 32p. (unpub. manuscript).

Wickware, G.M., D.W. Cowell and R.A. Sims. 1980. Peat resources of the Hudson Bay Lowland coastal zone. Proc. 6th Int. Peat Congress, Duluth MN: 138-143.

Woo, V., G.F. Mills, H. Veldhuis and D.B. Forrester. 1977. Biophysical land classification: Hecla-Carroll Lake, 62P-52M, Manitoba. Canada-Manitoba Soil Survey, Manitoba Dept Renewable Resources and Trans. Services: guide and 1:125,000 scale map.

Young, S. and A. Judge. 1985. A ground temperature data collection for northern Canada. Proc. McGill Workshop on Climate and Thermal Regimes in Northern Canada, November 8, 1985.

Zarnovican, R. and J-L. Belair. 1979. Les tourbières de la Baie James: la vegetation et les sols. Ecological Land Class. Ser. No. 9, Lands Dir., Environment Canada, Ottawa, Ontario: 37p.

Zoltai, S.C. 1988. Wetland environments and classification. Chapter 1. *In. Wetlands of Canada*. Ecological Land Class. Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 3-26.

Zoltai, S.C. and C. Tarnocai. 1969. Permafrost in peat landforms in northern Manitoba. Proc. 13th Annual Manitoba Soil Sci. Meeting: 16p.

Zoltai, S.C. and C. Tarnocai. 1971. Properties of a wooded palsa in northern Manitoba. *Arctic and Alpine Research*, 3(2): 115-129.

Zoltai, S.C. and C. Tarnocai. 1975. Perennially frozen peatlands in the western Arctic and Sub-arctic of Canada. *Can. J. Earth Sci.*, 12: 28-43.

Zoltai, S.C., C. Tarnocai, G.F. Mills and H. Veldhuis. 1988a. Wetlands of Sub-arctic Canada. Chapter 3. *In. Wetlands of Canada*. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publications Inc., Montreal, Québec: 57-96.

Zoltai, S.C., S. Taylor, J.K. Jeglum, G.F. Mills and J.D. Johnson. 1988b. Wetlands of boreal Canada. Chapter 4. *In. Wetlands of Canada*. Ecological Land Class. Series No. 24. Sustainable Development Branch, Environment Canada and Polyscience Publications Inc., Montreal, Québec: 97-154.

GLOSSARY

Alluvial
Pertaining to alluvium which is all material deposited by modern rivers including sediments laid down in river beds, flood plains and estuaries.

Bog
Bogs are "...peat-covered or peat-filled wetlands, generally with a high water table...The bog surface is often raised, or level with the surrounding wetlands, and is virtually unaffected by the nutrient-rich groundwaters from the surrounding mineral soils" (Tarnocai 1980).

Decomposition
The alteration of plant material by aerobic or anaerobic microorganisms resulting in a reduction of mass; decreasing porosity, C to N ratios and hydraulic conductivity; and increasing bulk density, water content (percent volume), and proportion of ash (mineral constituents).

Deflation
Refers to the removal of solid particles, such as sand grains, by wind (wind erosion).

Drift
All materials deposited by the action of glaciers and their associated meltwaters.

Drumlin
An elongated hill formed by the moulding of basal till by continental glaciers. They commonly form in large groups (drumlin fields) and are characterized by a high and steep up-ice slope (stoss slope) and a long, gradual down-ice slope (lee slope) which points toward the direction of ice flow.

Fen
Fens are defined by Tarnocai (1980) as "...a peat-covered or peat-filled wetland with a high water table which is usually at or above the surface...The waters are mainly nutrient-rich, minerotrophic waters from mineral soils".

Fibric
Non-decomposed to weakly decomposed organic material represented by a von Post field determination of 1, 2 or 3 (sometimes 4 as well). The most common fibric material in Canadian peatlands consists of sphagnum moss remains characteristic of bogs and poor fens. Organic soils composed largely of relatively undecomposed plant materials are classified as Fibrisols.

Flark
"... area of exposed peat with an algal film, sometimes having a sparse cover of sedges. Such areas are often locally frequent; though usually fairly small, some may be up to 1 km in length." (Gore 1983).

Glaciofluvial
Processes, features and deposits pertaining to rivers and streams supplied by glacier meltwater and occurring on, in or immediately in front of the ice. Deposits includes kames and eskers and are characterized by internal sorting and good stratification.

Glaciolacustrine
Processes, features and deposits pertaining to lakes which were formed at the front of retreating glaciers. Two major glacial lakes affecting the Northern Wetlands Study area are Lake Agassiz, which occupied most of Manitoba and northwestern Ontario, and Lake Barlow-Ojibway which occupied a large portion of northeastern Ontario and western Québec. Glacial lakes are characterized by rapidly fluctuating water levels and aerial extent. Sediments from these lakes consist of silts and clays.

Glaciomarine
Processes, features and deposits pertaining to marine incursions during late glacial and interglacial periods. Within the study area, glaciomarine deposits consisting of clays and silty clays cover nearly the entire Hudson Bay Lowland Physiographic District and portions of the Atlantic Sub-arctic Wetland Region of southern Labrador. The sea which occupied the Hudson Bay Lowland is known as the Tyrrell Sea. It originated during the last stages of glacial retreat via the Hudson Straight, 7,000 to 8,000 yrs BP.

Gyttja
Colloidal sediments originating from plant and animal remains which are not recognizable in terms of their original structure. Commonly used in association with post-Pleistocene lake in-filling (see terrestrialization).

Humic
A stage in the decomposition of organic material representing the most strongly decomposed peats. This corresponds to a field von Post of 7 or greater with original plant structure barely or not recognisable. Organic soils composed mostly of well decomposed materials are classified as Humisols.

Hummocks
"..of *Sphagnum* are thought to develop from hollows due to semi-aquatic *Sphagnum* spp. growing more quickly, and new hollows to be produced by inundation of the previously existing and slower growing vegetation (including lichens and dwarf shrubs) on the hummocks." (Gore 1983).

Isostasy
The point at which large portions of the earth's crust reaches a balance with the underlying denser mantle on which the crust floats. Glacial isostatic rebound refers to the restoration of the balance by crustal uplift following a prolonged period of downwarping due to the weight of the continental glaciers.

Krummholz
Stunted and deformed trees (usually used in reference to spruce) as a result of harsh climatic/soil conditions.

Levées
Levées are linear ridges which are located immediately adjacent to stream/river channels. They are composed of alluvium which was deposited by the rivers during flooding events.

Loam
Soils containing a mixture of grain sizes including clay, silt and sand are loams. It is also used to indicate specific textural classes such as loamy sands, coarse loamy, etc.

Marsh
Marshes are defined as "...a mineral or peat-filled wetland which is periodically inundated by standing or slowly moving waters. Surface water levels may fluctuate seasonally" (Tarnocai 1980).

Mesic
Moderately decomposed organic material intermediate between fibric (non- to weakly decomposed) and humic (strongly decomposed). It corresponds to a von Post field determination of 4, 5 or 6. Sedges and grass remains characteristically dominate mesic peats. Organic soils composed mostly of moderately decomposed plant materials are classified as Mesisols.

Minerotrophic
"A supply of water to vegetation originally derived from mineral soils or rocks but sometimes via lakes or rivers... it may be eutrophic, mesotrophic or oligotrophic." (Gore 1983).

Ombrotrophic
"A supply of nutrients exclusively from rain water (including snow and atmospheric fall-out), therefore making nutrition extremely oligotrophic often in an unbalanced way." (Gore 1983).

Outwash
Deposits of coarse materials (usually sands and gravels) laid down by running water (meltwater) in front of glaciers. It includes features such as outwash plains, sandurs, kame deltas, etc.

Paludification
The encroachment of organic terrain onto upland mineral terrain as a consequence of expansion, usually up-slope, of lowland peat deposits over time. Paludification of surrounding mineral terrain may result from continued deposition of organic material or may occur sporadically related to changes in climatic conditions more favourable to the growth and accumulation of organic material.

Physiognomy
Vegetation physiognomy refers to the structure and function of plants according to layers which have a specific appearance for different ecological types. Layers or strata of vegetation include tree, shrub, herb/sedge and moss/lichen and hence wetland physiognomic types include treed bog, graminoid fen, low shrub fen, etc.

Salt Marsh
Glooschenko et al. (1988) define salt marshes as "...marshes that are inundated by saline or brackish water from tidal marine sources".

Swamp
Swamps are defined as "peat-filled areas or mineral wetlands with standing or gently flowing waters occurring in pools and channels ...The water table is usually at or near the surface" (Tarnocai 1980).

Terrestrialization
The process of in-filling a lake or pond by organic materials resulting in the replacement of open water surfaces to surfaces capable of serving as a medium for plant growth. In-filling occurs directly via the deposition of material from surrounding watershed and/or the expansion of floating mats of vegetation from shore areas into the open lake or pond.

Terric
When applied as a modifier to organic soils, as defined by the Canadian System of Soil Classification, refers to the presence of a mineral substratum at least 30 cm thick between 40 and 160 cm from the surface of the peat.

Thermokarst
A karst-like topography common to permafrost areas. It is characterized by pits, hollows, hummocks and closed depressions created by the localized melting of ground ice.

Till
Glacial deposits laid down beneath (ground moraine) and in front of (recessional and terminal moraines) glaciers as well as deposited by melting out of receding glaciers (ablation till). Tills are characterized by a lack of internal stratification and a wide mixture of grain sizes (i.e., poorly sorted).

Typic
When applied as a modifier to organic soils, as defined in the Canadian System of Soil Classification, refers to the absence of mineral material 30 cm or thicker within 160 cm of the surface of the deposit.